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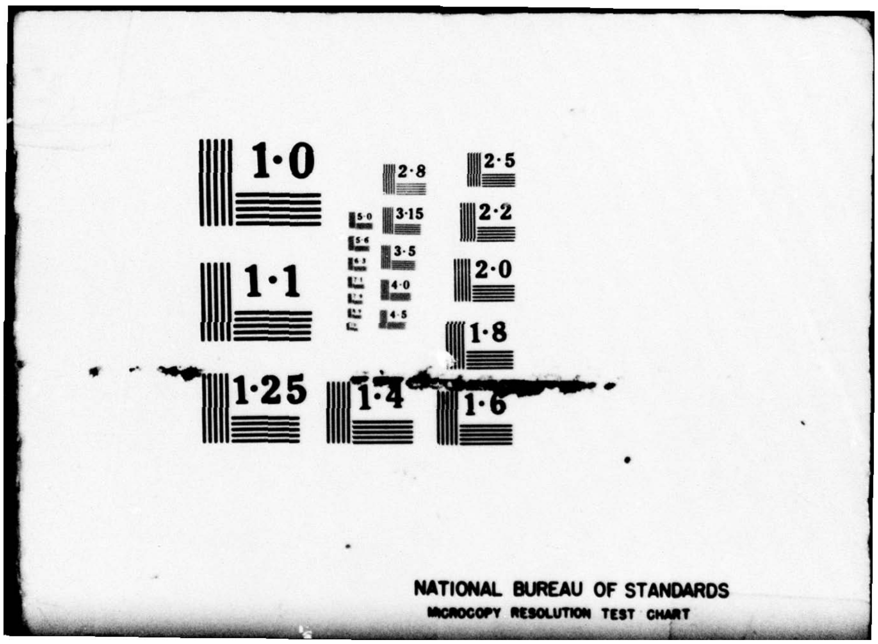
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FINAL REPORT

TEST AND EVALUATION OF THE TIME/FREQUENCY COLLISION AVOIDANCE SYSTEM CONCEPT

September 1973

Prepared for
ELECTRONIC SYSTEMS DIVISION
AIR FORCE SYSTEMS COMMAND
404L TRAFFIC CONTROL AND LANDINGS
SYSTEMS PROGRAM OFFICE
L. G. HANSCOM FIELD
Bedford, Massachusetts 01730
under Contracts F09603-72-A-1132-RS03
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A Time/Frequency Collision Avoidance System (T/F CAS) test program was conducted to provide a detailed representation of the capability and limitations of the T/F CAS concept. The results of this test program, together with results of tests of other CAS concepts, will be required for and utilized in the selection of any national CAS standard.

The T/F CAS test program involved flight testing, laboratory testing, and analysis of the flight and laboratory test data. The details of these efforts

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and the overall results and conclusions of the T/F CAS test program are presented in this report. Both commercial-air-carrier (FULL CAS) and general-aviation (MICRO CAS) equipments were evaluated. The equipments were found to measure range, range rate (FULL CAS only), and altitude separation with sufficient accuracy to provide warnings and alarms to aircraft at suitable times. Features of the T/F CAS concept that are essential to its operation, such as communications reliability, synchronization, susceptibility of interference, and resolution of time-slot co-occupancy, were evaluated and found to be acceptable for T/F CAS operation. The tests of normal en-route and terminal situations were supplemented by special test flights to demonstrate the performance of the T/F CAS equipments in infrequently occurring situations such as performance of the T/F CAS equipments in infrequently occurring situations such as supersonic encounters, encounters by T/F CAS-equipped aircraft operating in back-up mode, and three-aircraft encounters.

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Throughout the T/F CAS Test Program, ARINC Research received outstanding cooperation and support from the USAF Electronic Systems Division, the USAF Rome Air Development Center, the Air Force Eastern Test Range, and the McDonnell Douglas Electronics Company.

The Electronic Systems Division provided the test program with the aircraft, facilities, and personnel necessary to ensure a smooth and efficient operation. The Rome Air Development Center was responsible for the installation of the equipment in the aircraft and for supporting the aircraft at Patrick AFB. Both of these tasks were performed in a very timely and efficient manner. The Air Force Eastern Test Range provided excellent facilities and technical support throughout the test program. Finally, McDonnell Douglas provided valuable assistance to the test program through their professionalism and cooperation in the investigation of all aspects of the T/F CAS concept.

ABSTRACT

A Time/Frequency Collision Avoidance System (T/F CAS) test program was conducted to provide a detailed representation of the capability and limitations of the T/F CAS concept. The results of this ~~test~~ program, together with results of tests of other CAS concepts, will be required for and utilized in the selection of any national CAS standard. The test program involved

The T/F CAS resultant test program involved ~~flight testing~~, and laboratory testing, and analysis of the ~~flight and laboratory~~ test data. ~~The~~ details of these efforts and the overall results and conclusions of the T/F CAS test program are presented~~, in this report.~~ Both commercial-air-carrier (FULL CAS) and general-aviation (MICRO CAS) equipments were evaluated. The equipments were found to measure range, range rate (FULL CAS only), and altitude separation with sufficient accuracy to provide warnings and alarms to aircraft at suitable times. Features of the T/F CAS concept that are essential to its operation, such as communications reliability, synchronization, susceptibility of interference, and resolution of time-slot co-occupancy, were evaluated and found to be acceptable for T/F CAS operation. The tests of normal en-route and terminal situations were supplemented by special test flights to demonstrate the performance of the T/F CAS equipments in infrequently occurring situations such as supersonic encounters, encounters by T/F CAS-equipped aircraft operating in back-up mode, and three-aircraft encounters.

SUMMARY

The Air Force conducted a flight test and evaluation of the time/frequency collision-avoidance system (T/F CAS) concept, with ARINC Research Corporation providing assistance under Contracts F09603-72-A-1132-RS03 and F09603-72-A-1132-RS04. ARINC Research prepared a flight-test plan entitled "Development of a Test Plan for the Evaluation of the Time/Frequency Collision Avoidance Concept" in November 1972; this served as the basis for the flight-test program. The Company's efforts also included analyses of the flight-test data and laboratory tests and evaluations.

The T/F CAS test program was part of an ongoing joint DOT/DOD effort to evaluate candidate collision-avoidance concepts. A DOD CAS working group prepared a set of guidelines for these evaluations, and these were followed in the T/F CAS test program. The goal of the program was to provide a clear representation and evaluation of the capabilities of the T/F CAS concept. It was therefore necessary to determine the accuracy with which T/F CAS-equipped aircraft could evaluate potential threats, and to examine the special conditions or situations on which the T/F CAS concept is dependent.

The flight-test program was conducted at the Air Force Eastern Test Range (Cape Kennedy) during March 1973. The 14 missions defined in the test plan were flown, but only 10 separate test flights were required because some of the missions were combined. Two F-106A, one NKC-135, and two C-131B aircraft were used as test-bed aircraft. Both the FULL CAS and the MICRO CAS were evaluated during the tests. A series of special tests were conducted to evaluate the performance of the T/F CAS equipments in supersonic encounters, and in traffic patterns. In addition, the T/F CAS back-up mode and synchronization process were evaluated. The majority of the tests, however, were devoted to measuring CAS performance in two-aircraft encounters typically found to occur in the national air space.

The laboratory tests of the T/F CAS equipments were conducted immediately after the conclusion of the flight-test program. These tests were planned to verify the instrumentation calibration, to evaluate the CAS oscillator stabilities, to evaluate the effect of helicopter rotor blades on the CAS signals, and to supplement the flight-test evaluation of the operation of the T/F CAS in a dense aircraft environment. These tests were

performed as planned, but events uncovered during the flight-test program dictated that additional tests be performed. A possible CAS failure observed during one of the flight tests was traced to a failed solder connection, and two unexpected forms of RF interference that occurred during the test program were investigated in detail in the laboratory.

The data analysis was performed to develop statistical models to represent the CAS performance observed during the flight-test program and to characterize the performance of the CAS equipments during the special flight tests. The statistical analyses generated error models for the CAS range, range-rate, and altitude measurements, and a representation of the CAS communications reliability and synchronization process.

The T/F CAS range, range-rate, and altitude-measurement errors were approximated by the normal distribution. The normal distribution is specified by two parameters, the mean and the standard deviation, and representative values for the mean and the standard deviation for the FULL and MICRO CAS were found to be as follows:

Parameter	FULL CAS	MICRO CAS
Mean Range Error	0.015 n.mi.	0.001 n.mi.
Standard Deviation of Range Error	0.035 n.mi.	0.057 n.mi.
Mean Range-Rate Error	± 20 knots	
Standard Deviation of Range-Rate Error	40 knots	
Mean Altitude Error	25 feet	20 feet
Standard Deviation of Altitude Error	60 feet	80 feet

The exact errors measured for the various systems were used to compute the probability of generating CAS alarms at various ranges or times prior to an encounter for a few selected cases. A detailed analytical procedure is provided in this report to permit the statistical results determined during the test program to be extended to any aircraft-encounter situation of interest.

The overall T/F CAS communications reliability was found to be about 97.5%. This reliability should be acceptable for CAS operations. However, it was found that the CAS communications reliability was reduced when RF interference was present.

Time synchronization is a unique requirement of the T/F CAS concept. It was found that CAS equipments out of the range of a ground station may experience some initial delay in obtaining time-base synchronization, depending on the relative number and positions of the other aircraft that are providing synchronization. In this case, synchronization will be delayed until a synchronization-donating aircraft is found such that no other synchronization-donating aircraft are within 3 n.mi. of the same range. However, it was found that after synchronization has been obtained initially, a CAS will be able to maintain synchronization as long as a suitable synchronization donor is within range.

The three-aircraft encounters, supersonic encounters, T/F CAS back-up-mode tests, and traffic-pattern tests indicated that T/F CAS equipments can operate successfully under these situations. CAS circuit failures and problems with the CAS installations were uncovered during the conduct of these tests, but these specific problems were hardware-related and do not invalidate the basic T/F CAS concept.

The T/F CAS concept requires that the systems operate in separate time slots. The process of time-slot co-occupancy checking and resolution was investigated, and it was found that the CAS equipments will always find a time slot if there is one available.

The T/F CAS equipments were found to be susceptible to interference from the AN/APN-159A and AN/APN-155B radar altimeters and from the rotating beacon or Grimes light. The effect of interference was generally to reduce the communications reliability. However, the MICRO CAS also generated false alarms from the AN/APN-155B signals when tested in the laboratory.

Several unusual problems occurred during the test program that could be traced directly to CAS circuit failures. It was believed that these failures should not be allowed to affect the evaluation of the T/F CAS concept, but they do have a bearing on the overall results. One of the FULL CAS's had a failed solder connection that permitted this unit's time base to become grossly misaligned. This failure indicated the need for an improvement in both the MICRO CAS and FULL CAS time-synchronization logic to preclude serious time-base misalignments. One of the MICRO CAS's had a flip-flop in its altitude-decoding circuitry that failed intermittently. Although every effort was made to eliminate the erroneous altitude data from the statistical analysis, some of these data may have been included in the analysis. Therefore, the altitude-measurement capability of the CAS equipments may be slightly better than that reported in this document.

From the test and evaluation of the T/F CAS concept, it is concluded that the T/F CAS concept can provide a high probability of generating correct and properly timed warnings and alarms to prevent aircraft collisions. It is recommended that several minor system modifications be made to improve the overall operation of the T/F CAS concept, but none of these is critical to overall system operation. However, while it is recognized that partial CAS is probably better than no CAS, it is suggested that CAS's with fixed-range alarm boundaries (or no alarm boundaries such as would be the case in CAS-responder-only units) be avoided if at all possible.

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CHAPTER ONE

INTRODUCTION

1.1 BACKGROUND

The prevention of aircraft mid-air collisions has depended primarily on two elements. The first of these, which is pilot-dependent, is known as the "see and avoid" concept. The concept functions relatively satisfactorily under those visual and meteorological conditions that permit its use, as testified by the number of mid-air collisions it has prevented. However, it is also a fact that the largest number of near mid-air incidents occur when both aircraft are operating under VFR conditions and "see and avoid" is the only means of providing separation. Over the years, the concept has been made less reliable by the increasing number of higher-speed aircraft, creating a greater number of situations in which there may not be enough time to execute an evasive maneuver once visual contact has been established.

The second element is reliance on the existing air-traffic control (ATC) system to detect potential collision situations and provide evasive-maneuver advisories to the aircraft involved via the ground-to-air communication link. While it is broadly recognized that the ATC system is, and should continue to be, the backbone of a national collision-avoidance system, it is also recognized that collisions still occur, and there may be a requirement for a back-up system for those situations in which ATC is not available (e.g., over the ocean routes), does not contain information on all aircraft in a specific area, or experiences a system error or failure.

There are at present a number of techniques for providing some degree of collision avoidance, collision warning, and proximity warning. What is lacking is the evidence upon which a sound and logical choice can be made from among the candidate systems. The recent proliferation of conceptual solutions to the collision-avoidance problem and the high-level political interest brought about by recent mid-air collisions have accelerated the activities of a cooperative DoD/DOT/NASA program to collect the data necessary to allow the establishment of a national standard for a collision-avoidance system.

The military, through their Inter-Service Working Group on Collision Avoidance, have formulated a plan for investigating and validating candidate systems that might meet the requirements of the DoD for collision avoidance. It is planned that, at the end of this investigation/validation program, the DoD will be prepared to advise and assist the FAA in the possible establishment of a national standard for collision avoidance.

The Air Force has accepted the responsibility for assisting the FAA in evaluating the time/frequency (T/F) synchronous collision-avoidance system (CAS). The purpose of the effort described in this report was to assist the Air Force in this evaluation by conducting a flight and laboratory test program.

1.2 OBJECTIVES OF THE EFFORT

The primary objective of the USAF/ARINC Research Corporation evaluation of the T/F CAS concept was to provide the DoD and FAA with a comprehensive statistical representation of the technical performance characteristics of the T/F CAS hardware under realistic flight conditions. Because of resource limitations (e.g., aircraft and CAS equipments), no effort was required or made to duplicate the dense aircraft environment that is likely to be found in a busy terminal area. Suitable performance data on dense traffic conditions should be collected from a carefully designed but less expensive computer-simulation test program. The USAF T/F CAS test program was conducted at the Eastern Test Range (ETR) with CAS equipment supplied by the McDonnell Douglas Electronics Company.

The basic purpose of the tests was to obtain detailed engineering data on the communications-link performance, the ability of the internal CAS electronics to evaluate threats properly, and the statistical distributions of parameters measured by the CAS electronics. Some CAS testing designed to demonstrate the system performance in typical flight environments was conducted to gain additional engineering data, to demonstrate the system performance under commonly encountered scenarios (e.g., traffic patterns), and to provide a basis for comparison with other CAS concepts. It was also recognized that certain CAS hardware tests should be conducted in the laboratory.

The time/frequency concept is one method by which the data elements for computing critical Tau (time to collision) and altitude separation can be exchanged between aircraft. To provide a basis for comparison with other CAS concepts, the accuracy with which these data elements are exchanged was determined. For a complete representation of the performance of the CAS hardware, the susceptibility of this data-exchange process to such factors as electromagnetic interference was also determined. Factors unique to the T/F CAS concept, such as time synchronization and back-up mode operation, were also analyzed in detail. The test program therefore measured the accuracy of data exchange between aircraft and identified the conditions under which the T/F CAS concept could operate.

To minimize the cost of evaluating the accuracy of and conditions for operation of the T/F CAS hardware, several additional objectives were imposed on the T/F CAS test program. In 1969, the Air Transport Association (ATA) conducted an extensive evaluation of the then existing T/F CAS hardware, and the Air Force thought it advisable to make maximum use of these results. The ATA test program accumulated 211 system operating hours in which performance data were collected. More than 175,000 data points were recorded and analyzed. Therefore, the Air Force T/F CAS test program was designed to include the following:

- Tests not conducted (or not adequately conducted) during the Air Transport Association (ATA) flight-test and evaluation program

- Tests of new or modified CAS equipments not available for the ATA evaluation

- Selected operational environments or flight encounters not treated in the ATA evaluation

- Limited flight demonstrations of the previously untested equipments in some commonly encountered flight situations, as well as situations designed to stress the CAS system performance

The time/frequency concept allows for a range of capabilities of airborne CAS equipments, varying from extensive-capability "full" systems suitable for commercial airliners to "micro" systems intended for general aviation. A full system is one that complies with the full ANTC 117 threat logic. Because the ATA tests primarily evaluated full airborne systems, a secondary priority was given to an airborne reevaluation of the time/frequency concept in encounters involving two full systems. The micro system was not tested in the ATA evaluations because it was not available at the time the ATA tests were conducted. Thus a large part of the testing reported on herein was directed toward flight encounters involving one or more aircraft equipped with the micro systems.

A more complete description of the rationale for the ARINC Research flight-test program is presented in the Final Report, *Development of a Test Plan for the Evaluation of the Time/Frequency Collision Avoidance Concept*, ARINC Research Publication OC53-01-1-1200, November 1972.

1.3 SUMMARY OF THE EVALUATION APPROACH

The T/F CAS test program was primarily a flight-test evaluation designed to collect statistical data on the accuracy and communications-reliability performance of a set of CAS hardware representative of the T/F CAS concept. The airborne testing of the equipment was conducted during commonly encountered flight scenarios. In addition, laboratory tests were conducted to evaluate those aspects of the T/F CAS concept not amenable to flight testing.

The flight program consisted of a number of missions during which the CAS performance was monitored on each aircraft by using a combination of instrumentation sets. The three-dimensional coordinate positions of all test-bed aircraft were simultaneously determined by the use of precision metric tracking radars provided by the Air Force at the ETR. The errors in CAS-derived data (i.e., range, range-rate, and altitude differences between aircraft) were subsequently derived by comparing the data recorded by the CAS instrumentation sets in the aircraft with the metric tracking data collected on the ground by the range radars. Each of the missions flown constituted a separate experiment during which one or more tests of CAS performance were conducted in order to develop a data base for subsequent analysis.

The data collected were of two general types. The first type included data collected for the purpose of deriving statistical estimates of CAS operation. Typical of the results obtained from these tests were models and estimators for the errors in the basic CAS parameters, the reliability with which the CAS can communicate and process the signals necessary to establish the basic CAS parameters, and the frequency of either late or early CAS-generated advisories or maneuver commands.

The second type included data collected for use in probing each of the unique characteristics (e.g., synchronization support, back-up mode) of the T/F CAS concept. Typical of the results obtained from these tests were the frequency of acceptance and conditions with which synchronization signals could be processed, the performance of a mixture of full- and limited-capability CAS systems in some typical flight scenarios, the CAS operation during supersonic collision encounters, and the effectiveness of the CAS in its back-up-mode operation, during which synchronization support is not available.

The data collected during the flight phase of the evaluation program were augmented by a series of laboratory tests consisting of the following evaluations:

- Measurement of signal-delay times from the CAS equipment to the instrumentation sets for the purpose of making corrections in the recorded data
- Measurement of the CAS oscillator stabilities
- Evaluation of the susceptibility of the CAS equipments to unintentional electromagnetic interference from radar altimeters and pulse noise sources
- Verification of CAS equipment malfunctions and performance anomalies uncovered during the flight tests
- A limited simulation of high aircraft-traffic densities in order to evaluate the patterns and times associated with the slot selection and slot changing of the CAS equipments

- A limited evaluation of the effect of helicopter rotor-blade interference on CAS operation

1.4 REPORT ORGANIZATION

This report consists of a comprehensive summary, seven chapters, and eight appendixes. It can be read in part or in whole depending on the level of detail desired by the reader. Readers unfamiliar with the details of the T/F CAS concept of operation can obtain an overview of the results, conclusions, and recommendations of the test program by examining Chapters Six and Seven. However, if they desire a fuller appreciation of the rationale behind the type of test program conducted, they are strongly advised to peruse Appendix A, "Description of T/F CAS Concept and Hardware", before reading any of the other chapters in the report.

Chapter Two, "Description of Flight Test Program", describes the flight tests conducted during March 1973 at the ETR, the particular equipment implementations of the T/F CAS concept that were tested, and the two general types of instrumentation sets used to record the CAS parameters. This chapter concludes with a description of the types of data collected, the quick-look analysis procedures designed to insure that the CAS measurements had been recorded by the automated instrumentation and appeared reasonable, and the basic format of the CAS data bank from which all analyses would be derived.

Chapter Three, "Analysis of Flight Test Data", describes how the CAS data bank was exercised to develop a statistical characterization of the performance of the equipments tested. It shows how the range, range-rate, and altitude error data were analyzed and the error models and statistical estimators were developed for these parameters on an equipment-couplet basis (e.g., FULL CAS listening to another FULL CAS, MICRO CAS listening to a FULL CAS, etc.). Also discussed are communications reliability, synchronization-support aspects, performance during supersonic encounters, and back-up-mode operations of the CAS equipments. Some special probes of CAS performance under a selected number of flight situations designed to stress CAS operations are analyzed. The chapter concludes with a limited analysis of CAS range-rate errors assuming the implementation of a proposed modification of the T/F CAS concept. The modification would result in the derivation of range-rate information on the basis of incremental range comparisons versus the present method of doppler measurements. It was possible to use the existing data base to analyze the effects of this modification before implementing it.

Chapter Four, "Laboratory Testing of CAS Equipment", describes a series of bench tests that it was thought could be more reasonably conducted under the controlled conditions of a laboratory environment than in flight. Four types of laboratory tests were conducted, with objectives as follows: (1) to verify the calibration of the instrumentation systems, (2) to supplement the flight-test data results, (3) to test phenomena (e.g., electromagnetic interference) that are best examined in the laboratory, and (4) to verify and examine CAS operational anomalies encountered during the flight tests.

Chapter Five, "Special Problems Encountered During the T/F CAS Test Program", highlights and summarizes the unusual problems encountered during the flight-test program. The problems discussed include (1) the disruption of normal ground-station operation by an unexpected source of interference, (2) a case of false detection of one of the synchronization signals due to noise, (3) the gross misalignment of a CAS's time base due to a malfunction in a synchronization-signal logic gate, and (4) an intermittent malfunction in one of the MICRO CAS's causing the altitude codes from the encoding altimeter to be decoded improperly.

Chapters Six and Seven, respectively, present a discussion of the test program results and conclusions and recommendations.

The report is also supported by eight appendixes, prepared to provide the reader with a complete understanding of the technical details of both the T/F CAS concept and the test instrumentation, as well as the mathematical basis for the development of the statistical representations of CAS performance. These appendixes are as follows:

Appendix A - Description of the T/F CAS Concept and Hardware

Appendix B - Sample Mission Briefing Packets

Appendix C - Description of Test Instrumentation

Appendix D - Reliability and Maintainability Report, Model 2000 and 2002 Collision Avoidance Systems

Appendix E - Analysis of Variance

Appendix F - Analysis of the Effects of FULL CAS Range and Range-Rate Errors

Appendix G - Description of the CAS Traffic Simulator

Appendix H - Photographs of CAS Installations

In summary, this report contains the data, analyses, and models that characterize the T/F CAS concepts. Although a substantial quantity of data was collected, only a limited amount of analysis of this data is presented herein, basically because there is no commonly accepted single figure-of-merit for evaluating a CAS. The true effectiveness of a CAS is highly related to the scenarios in which it must operate; and it was, of course, impossible to test the operation of the T/F CAS concept in every conceivable scenario. Consequently, the CAS data bank was developed and the limited analyses were performed not only to provide immediate guidance but also to aid in any future analysis of the T/F CAS concept.

The conclusions presented in this report should not be interpreted as favoring either the adoption or rejection of the T/F CAS concept as a national standard for collision avoidance. A decision of this

magnitude should include additional considerations, equal in importance to the technical merits of the system, which were not considered during this evaluation program. However, it can be justifiably concluded that the performance of the T/F CAS concept was adequate to provide a high probability of ensuring safe aircraft separation under the situations tested.

CHAPTER TWO

DESCRIPTION OF FLIGHT-TEST PROGRAM

2.1 GENERAL COMMENTS

The purpose of the flight-test program was to provide engineering performance data on the T/F CAS equipments under a range of flight conditions. The flight conditions were chosen to be representative of potential aircraft encounters in the national airspace. Data were recorded from the T/F CAS equipments during these encounters by using photo panels, digital magnetic-tape instrumentation, and CAS-threshold video tape recording. In addition, aircraft-position data were recorded with tracking radar, and voice recordings were made of all air/ground communications.

The test flights were conducted very nearly as planned and discussed in the T/F CAS Test Plan, with fewer problems being encountered than were expected. Weather caused one flight to be postponed, one flight to be rescheduled because of poor visibility in the test area, and one mission to be changed after take-off because of low clouds. A tracking-radar failure caused one flight to be rescheduled; and one flight was postponed to allow time to correct several small equipment problems. The advance party of Air Force, ARINC Research, and McDonnell Douglas personnel, together with the instrumentation and CAS equipment, arrived at Patrick AFB on Saturday, 3 March 1973. The T/F CAS ground station was installed, all equipment checked out, coordination completed, and briefings conducted in time for the first test flight to be accomplished on Tuesday, 6 March. All mission profiles called for in the test plan were conducted successfully in that the missions planned to be flown were flown, with the desired data being collected. The last flight was conducted on 28 March.

2.2 PROGRAM ORGANIZATION

The DoD AIMS/TRACALS System Program Office, Electronics Systems Division, was the Air Force Program Office for the T/F CAS test program and had overall program responsibility. The Program Office provided inter-organizational coordination, prepared and conducted the mission briefings, and directed the conduct of the flight-test missions.

The Air Force Eastern Test Range (AFETR) provided facilities, operating personnel, communications, and other support as required in the conduct of the flight tests. The facilities and details of operational procedures are contained in Operations Directive No. 065, "Collision Avoidance System (CAS)",16 February 1973, prepared by AFETR. The operations directive also contains charts showing the tracks of the patterns flown for each of the planned flights. The AFETR computation facility provided the initial processing of the flight-test magnetic tapes. Tapes were also prepared with the metric data merged for direct entry into the CAS data base.

The T/F CAS equipments and instrumentation were installed in the test aircraft by Rome Air Development Center's (RADC) Flight Test Division, which also provided support during the flight test. RADC provided flight crews and maintenance for the aircraft they provided, as did the Armament Development and Test Center (ADTC) from Eglin AFP and the 49th Fighter Interceptor Squadron (ADC) from Griffis AFB.

The McDonnell Douglas Electronics Company provided T/F CAS equipments and instrumentation for the program. They also provided maintenance and engineering support for the equipment and for the program.

ARINC Research Corporation helped the Air Force prepare the flight-test plan and assisted ESD in directing and conducting the test program. ARINC Research provided the observer/operators for the project equipment and had responsibility for evaluation of the data and preparation of the test report.

2.3 FLIGHT-TEST OPERATIONS

The flight test as conducted differed in some minor details from the original plan as contained in *Development of a Test Plan for the Evaluation of the Time/Frequency Collision Avoidance Concept*, November 1972, ARINC Research Corporation Publication 0C53-01-1-1200. McDonnell Douglas provided interfaces for the Model 2000 FULL CAS equipments installed in the NKC-135 and C-131B (819) so that they could operate with the ATA instrumentation and it would not be necessary to fly the brass-board Test and Evaluation equipment. A T/F ground station was required to initialize the T/F CAS equipments prior to flight and to provide synchronization, but it was not planned originally to instrument the ground station. However, it was found that enough equipment was available to instrument the T&E ground station using ATA instrumentation. The data collected by the ground station later proved to be very useful. By using switch boxes that simulate an encoding altimeter, it was possible to operate two CAS equipments at the same time on the C-131 aircraft. This substantially increased the volume of data collected and provided a redundancy which was found later in the analysis to be very useful in the evaluation.

The order in which the tests were flown is shown in Table 2-1. The table shows the date, test code, mission number, aircraft involved, CAS equipments operated, and the test objective. The following are brief narrative descriptions of each of the test flights.

Table 2.1 FLIGHT SCHEDULE

Date	Test Code	Mission	Aircraft	CAS Type	Test Objective
6 March	B	11	Ground C-131B (804) C-131B (819) NKC-135 F-106A	M2002 M2002 M2000 M2000 M2000	Test Model 2002, MICRO CAS operation in the presence of multiple donors of synchronization.
		12	Ground C-131B NKC-135	M2002 M2002 M2000	Test ability of low altitude M2002 MICRO to obtain sync from high altitude sync donor.
7 March	A	9	F-106A F-106A	M2000 M2000	Supersonic encounters synchronized mode. Supersonic encounters back-up mode. High subsonic encounters synchronized mode.
8 March	C	14	C-131B (819) C-131B (804) NKC-135	M2002, M2000 M2002, M2000 M2000	Traffic simulator installed in ground station to test ability of test items to detect co-occupants and find and occupy a new time slot.
13 March	F	1			Radar failure - mission rescheduled to 16 March.
14 March	D	8	C-131B (819) C-131B (804) NKC-135	M2002 M2002 M2000	Test of compatibility of threat logic of M2002 with M2000 threat logic in three aircraft encounter with M2000 in the middle.
		10	C-131B (819) NKC-135	M2000 M2000	Back-up mode encounters.
16 March	F	1	C-131B (819) C-131B (804)	M2000, M2002 M2000, M2002	Two-aircraft encounters at low altitude.
20 March	G	2	C-131B (819) C-131B (804)	M2000, M2002 M2000, M2002	Two-aircraft encounters at 10,000' altitude, one aircraft climbing or diving.
21 March	H	3			Poor visibility in test area - mission rescheduled to the next day.
22 March	H	3			Low clouds in test area - changed mission to mission L.
	L	7	C-131B (804) C-131B (819)	M2000, M2002 M2000, M2002	Two-aircraft encounters at 10,000' altitude.
		4	C-131B (304) C-131B (819)	M2000, M2002 M2000, M2002	Two-aircraft encounters at 10,000' with AN/APN-159 radar altimeter operating in C-131 (819). This mission was added to the flight after take-off.
26 March	J	5	C-131B (804) C-131B (819)	M2000, M2002 M2000, M2002	Two-aircraft encounters at 10,000' and 2,000', one climbing, one diving. Attempted to append Mission 6, Radar Altimeter, but had equipment problems with the CAS equipment.
27 March	E	13	C-131B (804) C-131B (819)	M2000, M2002 M2000, M2002	Traffic pattern tests.
28 March	K	3	C-131B (804) C-131B (819)	M2000, M2002 M2000, M2002	Two-aircraft encounters at low altitude, one aircraft climbing or diving.
		6	C-131B (819)	M2000, M2002 M2000, M2002	Two-aircraft encounters at low altitude, AN/APN-159 in C-131 (819) operating.

Note: The numbers (804) and (819) relate to the tail numbers of the two C-131B test-bed aircraft used in the program.

Missions 11 and 12 Test Code B, conducted on 6 March

This was a test of the synchronization process. A Model 2002 MICRO CAS was located on the ground at the Cape Kennedy skid strip, and one installed in the C-131 (804) aircraft was made to orbit at 1,000 feet. In mission 11 three Model 2000 full systems were flown in patterns that caused the coarse-synchronization triads to progressively merge and separate in their time of receipt at the receivers and also to arrive at different power levels. The Model 2000 systems had been modified to reply to all synchronization requests. The test provided data for evaluating operation in the presence of the multiple signals that will exist when there are multiple synchronization donors within communication range of an aircraft requesting coarse-synchronization data.

During the conduct of Mission 12, two of the synchronization-signal donors landed and the KC-135 flew out to approximately 60 nm. at an altitude of 35,000 feet. It then flew back over the skid strip at a normal cruise speed of 450 knots. This exercise was a test of the ability of a low-flying MICRO CAS-equipped aircraft to obtain synchronization from a high-flying donor aircraft.

Mission 9 Test Code A, conducted on 7 March

This mission was a test of the operation of the Model 2000 full system in supersonic-speed encounters. The mission required two separate flights because the flight time, or endurance, of the F-106 when operated with continuous afterburner is fairly short. The flight altitude was restricted to 30,000 feet because the Model 2000 CAS was not designed for unpressurized operation and had only been tested at that altitude in anticipation of the test program. Two supersonic encounters were conducted during the first flight with the aircraft flying in a racetrack pattern and the CAS operating in the synchronized mode. On the second flight, two supersonic encounters were conducted with the CAS operating in back-up mode; then synchronization support was restored to obtain one additional encounter at a high subsonic speed in the synchronized mode. Coarse-synchronization support was terminated during the back-up mode encounters. As a result, the CAS equipment-decoded epoch-start triads from on-board noise sources and their epoch counts became out of step with the ground station and with each other and thus complicated the data-evaluation process. The noise source is suspected to have been the Grimes light, which was in close proximity to the CAS antenna.

Mission 14 Test Code C, conducted on 8 March

This mission comprised the multiple-aircraft test. During the test, a traffic simulator was attached to the ground station to enable time slots to be "filled" in any quantity and pattern desired. The slots were filled by transmitting an eight-microsecond pulse, which caused the CAS receivers to assume that the slots were occupied. During this test, interference was

experienced from the AN/APN-155B radar altimeter operated on the F-4 Phantom aircraft. The AN/APB-155B transmits a frequency-modulated signal whose spectral level is quite strong at the highest of the CAS operating frequencies (1615 MHz), denoted as F-4. The presence of this interference caused the T&E CAS used as a ground station to suspend providing fine-synchronization support to the test aircraft while the F-4 aircraft was near PAFB.

Missions 8 and 10 Test Code D, conducted on 14 March

These missions were comprised of the three-aircraft encounters and the two-aircraft back-up mode encounters. The three-aircraft encounters were conducted to test the compatibility of the MICRO CAS threat logic with the FULL CAS threat logic in flight situations where the FULL CAS-equipped aircraft would be restricted from maneuvering because of the presence of a third aircraft. Interference from AN/APN-155B radar altimeters was experienced during the early part of the mission. At the suggestion of ARINC Research Corporation, the Model 2000 CAS installed in C-131 (804) aircraft was later modified by the addition of a Precision Frequency Unit ("PFU") switch that would make the equipment operate as if it had a precision frequency unit as a frequency reference. When interference caused the ground station to suspend fine-sychronization support, the switch was put in the PFU position, slowing the CAS's hierarchy countdown, and consequently preventing the aircraft from demoting into back-up mode. For the back-up mode encounters, the coarse-synchronization support by the ground station was retained, and no problems were encountered in keeping the epoch counts in step. During the course of this mission, the ground transmitter for one of the two radio links used during the tests failed briefly; thus considerable difficulty was experienced with project communications. The vector-control communications were unaffected. After completion of the mission, and during the return to base, the AN/APN-159A radar altimeter underwent a check-out in preparation for a future mission during which the effect of interference from the altimeter would be tested.

Mission 1 Test Code F, conducted on 16 March

This mission consisted of two-aircraft encounters conducted at low altitude. Interference with the ground station from F-4 aircraft was experienced on five of the test encounters, but the "PFU" switch modification prevented it from disturbing the conduct of the mission. After the F-4 aircraft left the vicinity of the CAS ground station, the time-base drift of the CAS airborne equipments was checked and found to be less than one microsecond.

Mission 2 Test Code G, conducted on 20 March

This mission consisted of two-aircraft encounters conducted at 10,000 feet with one aircraft climbing or diving to penetrate the protection envelope. Three of the encounters were repeated because of tracking-radar

problems. The loss of airspeed during the climb portion of the encounter caused problems in getting the aircraft to penetrate the CAS protection envelope; adjustments were therefore made in positioning the aircraft for the climbing encounters.

Missions 7 and 4 Test Code L, conducted on 22 March

Mission 3 Test Code H, was attempted, but since low clouds were still present, the mission was changed by the Air Force Test Director to Mission 7, which consisted of two-aircraft encounters at 10,000 feet altitude. Mission 4, as originally planned, was to be two-aircraft encounters at 10,000 feet altitude, with the first half of the mission providing reference data for the second half, which included operation of the AN/APN-159A radar altimeter as a potential interference source. Since Mission 7 would provide the desired reference data, the second half of Mission 4 was flown immediately following completion of Mission 7 on the recommendation of the USAF test director.

Mission 5 Test Code J, conducted on 26 March

This mission consisted of two-aircraft encounters at 10,000 feet altitude and then at 2,000 feet altitude, with one aircraft climbing and one aircraft diving. The high-altitude encounters were completed, and the fifth of the low-altitude encounters was completed when the Model 2000 FULL CAS in the C-131 (819) aircraft skewed its time base by 300 microseconds early. The Model 2000 CAS then captured the Model 2002 CAS that was also on the C-131 (819) aircraft by realigning its time base to agree with that of the Model 2000. Having skewed its time base, the Model 2000 CAS was unable to obtain fine synchronization. Consequently, it demoted into back-up mode and resynchronized. The Model 2000 CAS's epoch count became misaligned by two counts in the process.

The remainder of the low-altitude encounters were completed, and an attempt was made to fly the AN/APN-159A radar altimeter interference tests of Mission 6, but the Model 2000 CAS in the C-131 (819) aircraft again skewed its time base by 300 microseconds early. This time it captured both Model 2002 MICRO CAS's before it demoted into back-up mode and became resynchronized. At this time a malfunction in the Model 2002 MICRO CAS in the C-131 (804) aircraft prevented it from going into standby mode so that it could also be resynchronized. The situation had become too confused to be diagnosed quickly; consequently, the mission was terminated. The malfunction in the Model 2000 CAS turned out to be a failed solder connection in the fine-synchronization gate circuitry, which caused a gate to be open continuously instead of being open only at the prescribed time of 1419.2 $\pm$ 20 microseconds. This open gate allowed a false fine-synchronization

triad to be accepted; the false triad recognition is thought to be the result of decoding the distorted reflection of the CAS's own altitude pulse. (The reflection is suspected to be from a building at Cape Kennedy.)

Mission 13 Test Code E, conducted on 27 March

This mission was a test of CAS behavior in "encounters" which occur in typical airport traffic patterns. The field used for the testing was the skid strip at Cape Kennedy. Since the aircraft were always near or below the radio horizon of the ground station, the PFU switch on the Model 2000 CAS in the C-131 (804) aircraft was used to avoid system demotion into back-up mode. Fine-synchronization support from the ground station was inhibited, and the time-base drift was checked after the test patterns had been completed. The time-base drift that occurred after 1 hour 37 minutes was found to be 20 microseconds. This drift rate is 3.4×10^{-9}, which is well within the desired drift rate of 1×10^{-8}.

Missions 3 and 6 Test Code K, conducted on 28 March

Mission 3 consisted of two-aircraft encounters at low altitude, with one aircraft climbing or diving to penetrate the protection envelope. Mission 6 involved two-aircraft encounters at low altitude with the AN/APN-159A radar altimeter operating such as to cause potential interference with CAS operation. Interference from F-4 aircraft radar altimeters was experienced early in the mission; therefore, the mission was flown using the PFU switch on the Model 2000 CAS in C-131 (804) aircraft. When the mission was completed, the time-base drift over the 2-hour 8-minute period was found to be 2.6 microseconds. The drift was less than on the previous mission because fine-synchronization support was maintained long enough for the Model 2000 CAS oscillator to settle completely.

2.4 MISSION BRIEFINGS

Detailed mission briefings were prepared and presented by the ESD Project Office personnel before each mission, and copies of briefings were distributed to all mission participants. The briefings, examples of which appear in Appendix B, identified the mission and mission objective; presented diagrams of the flight tracks and profiles; listed the aircraft and the CAS equipments to be operated; listed the aircraft call signs; identified primary and alternate radio frequencies; contained operating procedures, safety restrictions, and abort procedures; and detailed the step-by-step conduct of the mission from engine start to return to base.

2.5 T/F CAS TEST HARDWARE

The types of T/F CAS equipment used in the test program were the EROS II Model 2000 FULL CAS, the EROS II Model 2002 MICRO CAS, and the Test and Evaluation (T&E) model originally used in the ATA/Martin-Baltimore flight tests conducted in 1969-70. The T/F CAS equipments were designed and built by the McDonnell Douglas Electronics Company and were made available for testing under a contract with the Air Force. All of these equipments had been built prior to this test program, and each had already accumulated an appreciable number of operating hours. Four Model 2000 CAS equipments were available, and all four were flown. Four Model 2002 CAS equipments were available, of which three were flown. Two T&E Models were available for use as a ground station, but only one of them was operated; the spare unit never had to be used. The operating hours accumulated during the flight tests were:

<u>Model 2000 CAS</u>

Serial No. 1		43.3 hours
Serial No. 2		45.9 hours
Serial No. 3		12.2 hours
Serial No. 4		11.1 hours
	Total	112.5 hours

<u>Model 2002 CAS</u>

Serial No. 1		10.7 hours
Serial No. 3		46.8 hours
Serial No. 4		46.8 hours
	Total	104.3 hours

The T& E unit accumulated 50.5 hours of operation, providing synchronization support to the other systems. The operating time accumulated during preflight and postflight check-outs is included in the hourly figures. The system flight hours during which performance data were recorded totaled 97 system hours.

The following are brief descriptions of the T/F CAS equipments used in the test program. The description of the operation of the T/F CAS concept and the various types of T/F CAS equipments is detailed and complex; therefore, that information is contained in Appendix A.

2.5.1 EROS II Model 2000, FULL CAS

Subsequent to the flight-test program conducted in 1969-70 by ATA/ Martin-Baltimore, ARINC Characteristic No. 587, "Air Transport Time/ Frequency Collision Avoidance System", was issued*. The EROS II Model 2000 CAS units used in the Air Force test program were designed in conformance with ARINC Characteristic No. 587 and were built as engineering models of equipment suitable for airline use.

The Model 2000 CAS is a full system as defined in ANTC Report No. 117** and ARINC Characteristic No. 587. (See Appendix A for a more detailed description of CAS operation.) It has the following unique capabilities and features.

Synchronization Donor - When operating in the synchronized mode, the Model 2000 CAS provides coarse and fine time synchronization to other airborne systems needing the service. At the beginning of each "air" epoch it transmits the "air" epoch start triad to provide coarse synchronization. During "air" epochs it transmits fine-time-synchronization replies to limited CAS systems and to any full system that transmits an all-call fine-synchronization request, i.e., hierarchy 63 and address 2047. It transmits fine-synchronization replies to other full systems when specifically addressed by the requesting full system.

Bi-Phase Modulation - It is capable of transmitting bi-phase modulation during the middle 120 microseconds of the 200-microsecond range pulse. This bi-phase modulation is used to provide control of the air-to-air synchronization process. The information transmitted by bi-phase modulation is hierarchy, synchronization request address, and identity.

Hierarchy - Hierarchy is a numerical value from zero to 63 which corresponds to the probable time-synchronization error. Small hierarchy numbers correspond to small errors, and each hierarchy step represents 0.05 microsecond. A full system will accept fine synchronization only from a known donor and will request fine synchronization only from a donor having a smaller error than its own, as indicated by the donor's transmitted hierarchy. Upon receiving fine synchronization, the full system adopts a hierarchy value one larger than that of the donor.

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*This ARINC document sets forth the basic requirements for a time/frequency collision-avoidance system specifically designed for installation in all types of commercial transport aircraft.

**Airborne Collision Avoidance System", Report No. 117, originally issued June 30, 1967 by Air Navigation/Traffic Control Division, Air Transport Association of America; prepared under the auspices of the CAS Technical Working Group, Airline Air Traffic Control Committee.

Fine-Synchronization Request Address - Fine-synchronization request address is used to request fine synchronization from a specific donor by transmitting the donor's address (slot number). This addressing capability permits a full system to select the best hierarchy available to be the synchronization donor. It also provides the control required to assure that fine time synchronization is always requested, and obtained, from a system having a smaller time-synchronization error.

Back-Up Mode (BUM) - An asynchronous mode (back-up mode) is provided as an alternate to the synchronized mode. BUM provides collision protection in low-density traffic areas where master time is unavailable. It uses an interrogator/responder operation in which the responder replies only if the altitude separation is within the protection band. The reply contains a maneuver instruction which the interrogator will follow if the round-trip time shows that the aircraft are within the range limits of the protection envelope.

Precision-Frequency Unit - The system has provision for using an external atomic oscillator as a substitute for its internal crystal oscillator. When a precision-frequency unit is used, the hierarchy rundown rate is slowed so that BUM is not resorted to until 55-1/2 hours have elapsed since the last receipt of fine synchronization. If the precision frequency unit should fail, the system will automatically revert to the internal crystal oscillator.

Built-In Test (BIT) and Automatic Test Equipment (ATE) - The system has BIT incorporated in the design and has a connector for ground testing by automatic test equipment. There are two BIT failure indicators. One of them monitors the continuity of the antenna circuit and the other monitors overtemperature and functional status. The functional-status items monitored are the internal oscillator, bi-phase data, range-altitude-triad pulse encoding and decoding, RF power, and doppler scaling. BIT checks that affect the indicator flag are input power, oscillator warmup, 5-MHz oscillator and basic timing, encoding altimeter input, transmit inhibit switch, oleo switch, approach/departure switch, receiver sensitivity, and interference jamming.

Threat Logic - The Model 2000 CAS has the full threat logic as described in ANTC 117 and ARINC Characteristic 587. The inputs to the threat logic that are used in evaluating threats are range, range rate, altitude difference, and own-altitude rate. It also accepts inputs from the oleo switch and the approach/departure switch. The outputs from the threat logic, which appear as displays on the CAS maneuver indicator, are discussed below.

Maneuver Indicator - Maneuver indicators, as shown in Figure 2-1, are provided for both pilot positions. The CAS display is combined with the Inertial-Lead Vertical Speed Indicator (IVSI). The CAS portions of the CAS/IVSI instrument are:

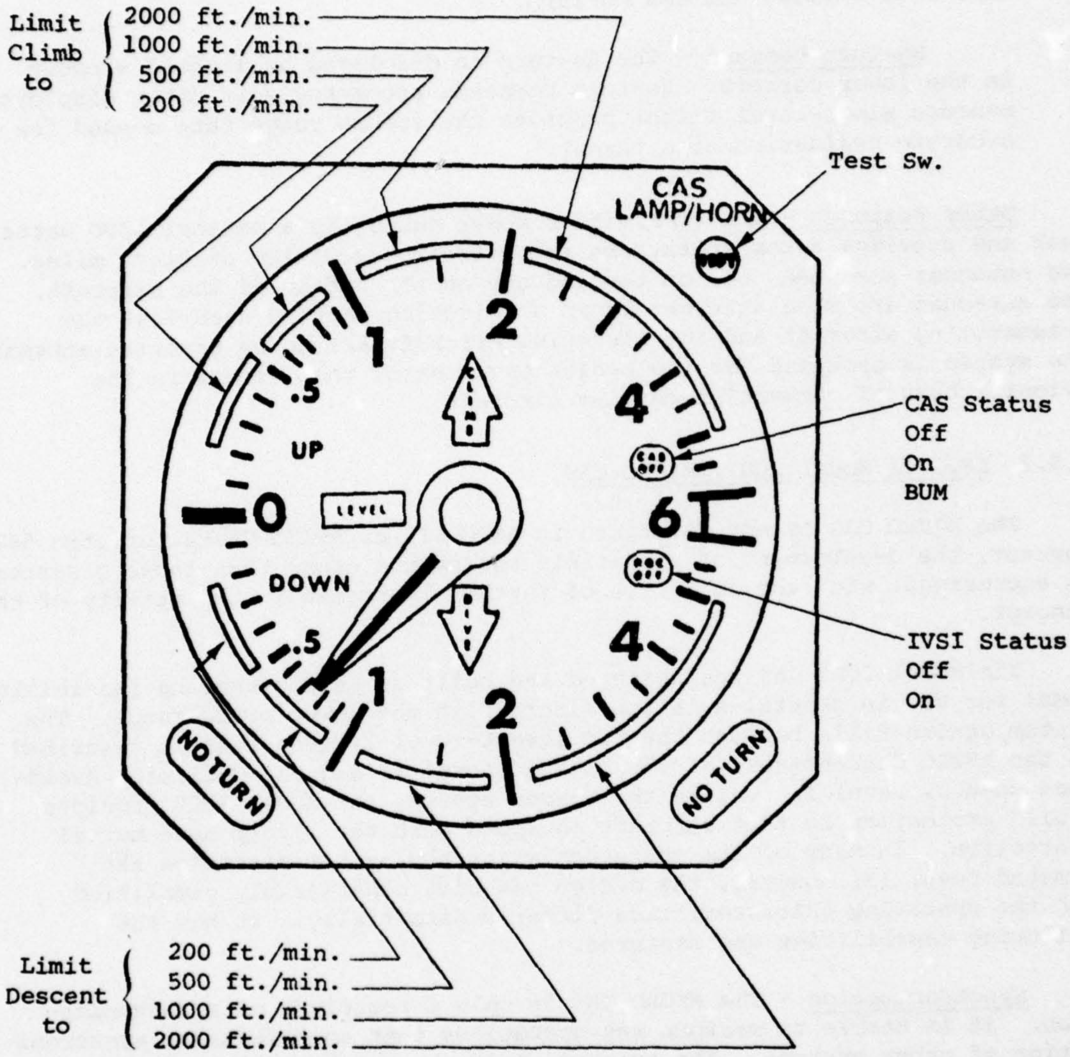


Figure 2-1. TYPICAL COMBINATION INSTRUMENT FACE (CAS/IVSI)

Vertical Speed Limits - The climb/dive rate limitations are displayed as lighted yellow segments around the periphery of the dial.

Climb/Dive Commands - The climb/dive commands are displayed as appropriately labeled and oriented red arrows placed above and below the pointer axis. A climb or dive display is always in combination with vertical-speed-limitation and no-turn displays.

Level-Off Command - The level-off command is displayed as a red bar at the nine o'clock position with the word "level" on it. A

level-off command will always be accompanied by both climb- and dive-rate limitations and no-turn.

No-Turn Command - The no-turn is displayed as lighted windows in the lower corners. No-turn commands accompany most other displays because wings-level flight provides the stable range rate needed for accurate evaluation of a threat.

Other Features - The transmitter power output is a nominal 1000 watts peak and provides a communications range in excess of 100 nautical miles. Two antennas are used, one on top and one on the bottom of the aircraft. The antennas are used alternately in a switching pattern such that the transmitting aircraft and the listening aircraft are using opposite antennas. The system is packaged for the benign environment that exists in the avionics bays of commercial-carrier aircraft.

2.5.2 EROS II Model 2002, MICRO CAS

The MICRO CAS is not described in ANTC-117 or ARINC Characteristic 587; however, the development of compatible equipments other than those described is encouraged, with the objective of further increases in the utility of the concept.

The Model 2002 CAS was designed and built as an engineering feasibility model for use in general-aviation aircraft in the lower price range. The system design falls between the two lowest-level limited systems described in the ARINC Characteristic: the Limited Level II and the Collision Avoidance Beacon, Level I. Unlike the beacon system, the Model 2002 provides "full" protection in that aircraft equipped with the system have mutual protection. In many of its characteristics the system resembles the Limited Level II; however, the design has been considerably simplified and the operating characteristics differ substantially. It has the following capabilities and features.

Synchronization - The MICRO CAS is only a recipient of synchronization. It is unable to perform any operations that contribute to synchronization of other systems. Its transmissions are interpreted by fine-synchronization donors as "all-call" requests for fine synchronization; thus synchronization donors automatically reply to the MICRO CAS even though they were not specifically addressed. To avoid excessive interference caused by multiple replies, the airborne synchronization donors do not reply to 100% of the requests. The probability of reply to a request is 1/N, where N is the number of full systems the synchronization donor can hear.

Bi-Phase Modulation - The Model 2002 CAS does not transmit bi-phase modulation in its range pulse nor is it capable of detecting and using the bi-phase modulation contained in received range pulses. Without bi-

phase modulation the system is unable to request synchronization from a specific donor and is also prohibited under the concept from supplying fine synchronization to other systems.

Operating Frequencies - The Model 2002 CAS listens on all four CAS frequencies but it transmits on only one frequency. None of the Model 2002 CAS equipments will transmit on frequency F-1 (1600 MHz); hence, they do not transmit epoch-start triads. Each system will be configured to transmit on one, and only one, of the remaining frequencies, F-2, F-3, or F-4. This restriction to a single frequency restricts the MICRO CAS to using the 500 time slots that correspond to its transmitting frequency.

Back-Up Mode (BUM) - The Model 2002 CAS is unable to participate in BUM operations. BUM operations are conducted exclusively on frequency F-1, and the Model 2002 CAS cannot transmit on that frequency. Not having BUM, the system will cease to transmit if fine synchronization is lost.

Reference Oscillator - The ANTC 117 specification for oscillator stability of limited systems is 2×10^{-8}. The oscillator in the Model 2002 CAS is a good-quality crystal oscillator without special provisions, such as a temperature-stabilized oven, for frequency stability. The oscillator is positioned in the packaging to improve its thermal stability, and there is frequency-correcting circuitry that keeps the frequency within tolerances through the fine-synchronization process.

Built-In Test - The Model 2002 CAS design does not include provisions for built-in test. Failures in the system will probably interrupt the fine-synchronization process, and the system will cease to transmit.

Threat Logic - The Model 2002 CAS does not have provisions for measuring the doppler shift in the received range pulses. Therefore, the parameters it measures as inputs to the threat logic are range and altitude only. Since it is intended for low-performance aircraft, there is no provision for own-altitude rate. The unavailability of range-rate information forced the selection of the protection-envelope boundaries at fixed ranges, as shown in Figure 2-2. The fixed boundaries and the limited vertical-speed capability considerably simplified the threat logic and maneuver indicator. The threat-logic matrix is shown in Figure 2-3, which is extracted from an instruction sheet prepared by McDonnell Douglas for pilots of aircraft having the MICRO CAS installed. The maneuver indicator as shown in Figure 2-4 is quite simple.

Other Features - The Model 2002 is designed for small aircraft. The indicator and electronics can be mounted together, or the indicator can be mounted in the instrument panel with the electronics mounted remotely. The system uses only one, simple quarter-wave stub, antenna mounted on the top of the aircraft. The input power is 12 volts d.c., and the transmitter power output is 200 watts peak, yielding a communications range in excess of 50 nautical miles.

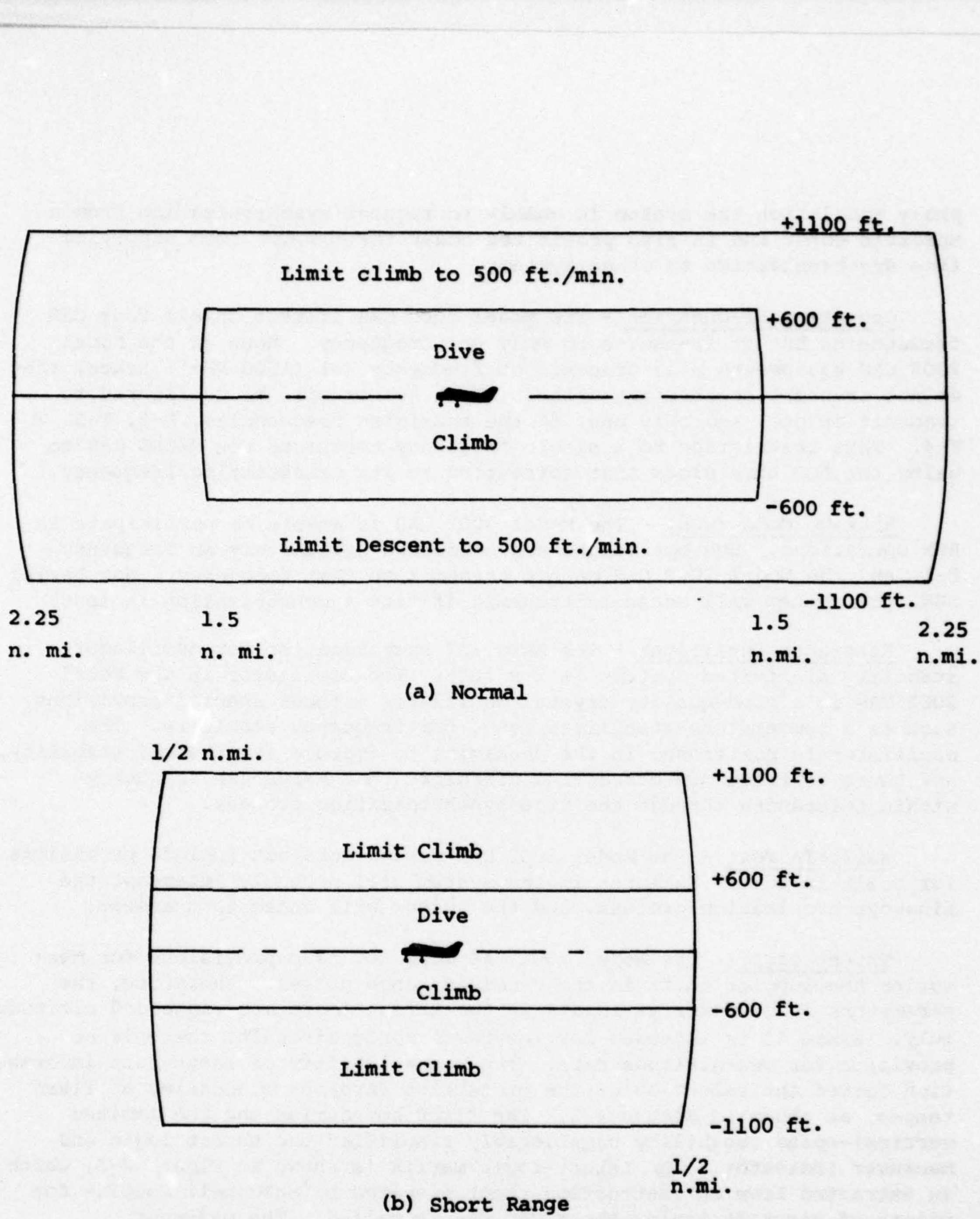
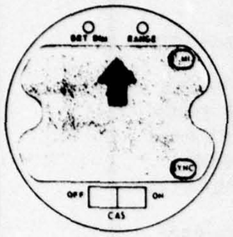
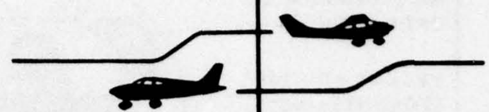
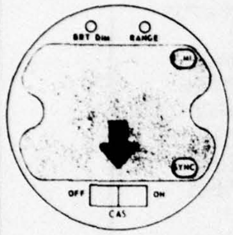
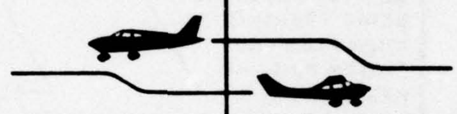
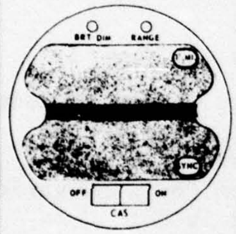
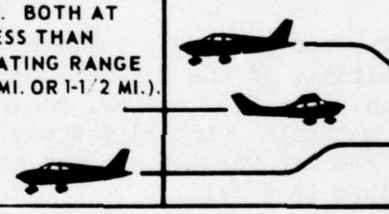


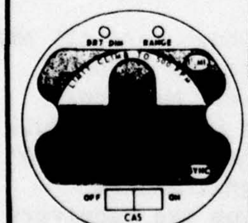
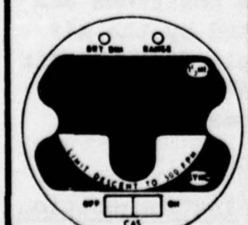
Figure 2-2. MICRO CAS, PROTECTION ENVELOPES

2.5.3 Test and Evaluation Model CAS (T&E)

The T&E model was designed and built by McDonnell Douglas as an experimental model for use in the 1969-70 flight-test program conducted by Martin-Marietta Corporation, Baltimore Division, for the Air Transport Association. This equipment is large (360 pounds), and its transmitter and receiver performance are not representative of current designs. It could not reasonably be used to test the present T/F CAS performance, but it was suitable for use as a ground station.

COMMAND	INDICATIONS	CONDITION	PILOT ACTION
	FLASHING RED CLIMB ARROW AND A CONTINUOUS BEEPING TONE.	ANOTHER AIRCRAFT 0-700 FT. BELOW AT A RANGE LESS THAN THE OPERATING RANGE MODE (1/2 MI. OR 1-1/2 MI.).	ROTATE AIRCRAFT TO ESTABLISH AND MAINTAIN BEST RATE OF CLIMB UNTIL COMMAND CEASES. 
	FLASHING RED DIVE ARROW AND A CONTINUOUS BEEPING TONE.	ANOTHER AIRCRAFT 0-700 FT. ABOVE AT A RANGE LESS THAN THE OPERATING RANGE MODE (1/2 MI. OR 1-1/2 MI.).	REDUCE POWER TO ESTABLISH AND MAINTAIN MAXIMUM NORMAL DESCENT UNTIL COMMAND CEASES. 
	FLASHING RED HOLD ALTITUDE BAR AND A CONTINUOUS BEEPING TONE.	ONE AIRCRAFT 0-700 FT. ABOVE AND ANOTHER AT 0-700 FT. BELOW. BOTH AT RANGES LESS THAN THE OPERATING RANGE MODE (1/2 MI. OR 1-1/2 MI.).	MAINTAIN PRESENT ALTITUDE UNTIL COMMAND CEASES. 

MICRO-CAS COMMANDS

ADVISORY	INDICATIONS	CONDITION	PILOT ACTION
	STEADY ILLUMINATED YELLOW LIMIT CLIMB TO 500 FPM SEGMENT. ALSO A 1.5 SECOND TONE AT ONSET OF INDICATION ONLY.	ANOTHER AIRCRAFT 800-1000 FT. ABOVE AND WITHIN THE MICRO-CAS PROTECTION ENVELOP RANGE; OR, ANOTHER AIRCRAFT LESS THAN 800 FT. ABOVE BUT AT A RANGE GREATER THAN THE OPERATING RANGE MODE (1/2 MI. OR 1-1/2 MI.).	IF CLIMBING, LIMIT RATE OF CLIMB TO LESS THAN 500 FPM, OTHERWISE NONE. REMAIN ALERT FOR POSSIBLE STATUS CHANGE FROM ADVISORY TO COMMAND.
	STEADY ILLUMINATED YELLOW LIMIT DESCENT TO 500 FPM SEGMENT. ALSO A 1.5 SECOND TONE AT ONSET OF INDICATION ONLY.	ANOTHER AIRCRAFT 800-1000 FT. BELOW AND WITHIN THE MICRO-CAS PROTECTION ENVELOP RANGE; OR, ANOTHER AIRCRAFT LESS THAN 800 FT. BELOW BUT AT A RANGE GREATER THAN THE OPERATING RANGE MODE (1/2 MI. OR 1-1/2 MI.).	IF DESCENDING, LIMIT RATE OF DESCENT TO LESS THAN 500 FPM, OTHERWISE NONE. REMAIN ALERT FOR POSSIBLE STATUS CHANGE FROM ADVISORY TO COMMAND.

MICRO-CAS ADVISORIES

Figure 2-3. MICRO CAS INDICATOR DISPLAYS

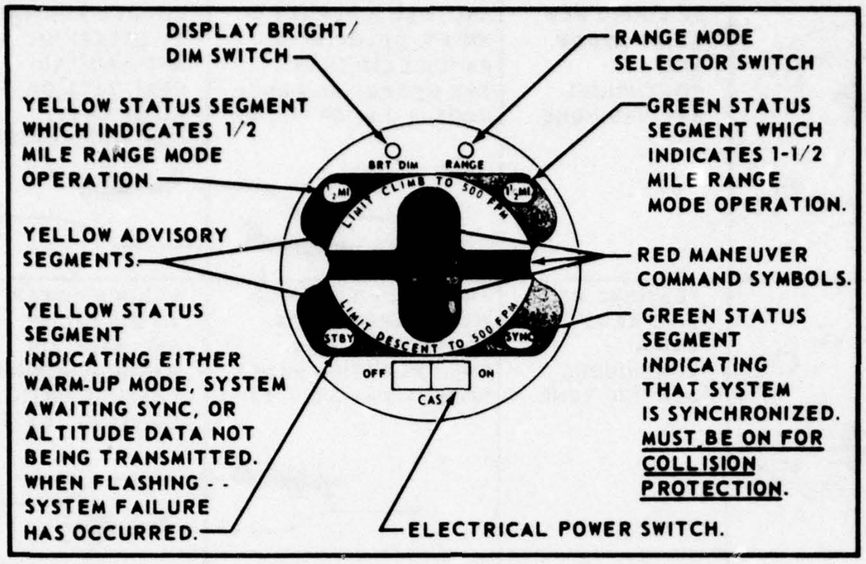


Figure 2-4. MICRO CAS INDICATOR

The T&E model was designed to provide the versatility needed to test the validity of the T/F CAS concept. It could be operated as a ground station, as a full system, or as a limited system. By means of front-panel controls, virtually every parameter of its operation could be varied. Since the T&E was not an item being tested, the equipment is not described in detail.

2.6 INSTRUMENTATION

The types of CAS instrumentation used in the flight test were (1) ATA instrumentation designed and built by Martin-Baltimore for the 1969-70 flight tests, as modified by ARINC Research Corporation, (2) McDonnell Douglas instrumentation designed for use with the EROS II Model 2000 full CAS, (3) McDonnell-Douglas instrumentation designed for use with the EROS II Model 2002 MICRO CAS, and (4) video recorders with signal mixers designed by ARINC Research to record raw video signals from the receivers of the MICRO CAS. Tracking radars with associated computers, plotters, recorders, and displays for collecting metric data on the positions and velocity vectors of the aircraft were provided and operated by the Air Force Eastern Test Range. The aircraft, with crews, supplied by the Air Force as test beds were C-131B (two), F-106A (two), and NKC-135 (one). The distribution of the instrumentation and T/F CAS equipments was as follows:

Aircraft	T/F CAS Type	Instrumentation
C-131B (819)	Model 2000 (full)	ATA
C-131B (819)	Model 2002 (MICRO)	MDEC & Video Recorder

(continued)

Aircraft	T/F CAS Type	Instrumentation
C-131B (804)	Model 2000 (full)	MDEC
C-131B (804	Model 2002 (MICRO)	MDEC & Video Recorder
NKC-135 (125)	Model 2000 (full)	ATA
F-106A (069)	Model 2000 (full)	MDEC
F-106A (075)	Model 2000 (full)	MDEC
Ground Station	T&E	ATA

The two F-106A aircraft and the NKC-135 were used first, at the beginning of the flight testing. The test hardware used in the F-106A (069) was then transferred to the C-131 (804) aircraft, and the test hardware in the F-106A (075) aircraft became spare equipment for the test program. The full CAS that was installed in the NKC-135 also became spare equipment.

2.6.1 ATA Instrumentation

The ATA instrumentation (see Appendix C for detailed description) was designed and built by the Martin-Marietta Corporation, Baltimore Division, for the T/F CAS flight-test program conducted in 1969-70 under the sponsorship of the Air Transport Association. Three sets of this instrumentation were leased from the ATA for the Air Force test program. Each of the sets was reassembled and checked and then was modified by ARINC Research as required to adapt it to the T/F CAS equipment that was to be tested.

The ATA instrumentation uses the Honeywell Micro-PAC series digital circuitry. The memory is a Honeywell ICM-42 core stack memory with a capacity of 2048 words of seven bits each. The digital electronics are contained in two Honeywell chassis boxes. The other items which make up the ATA instrumentation are (1) power-distribution panel; (2) instrumentation control panel; (3) analog-to-digital converter; (4) seven-track digital recorder; and (5) photo panel containing Nixie tube real-time displays, the CAS indicator, and some aircraft flight instruments. The photo panel data are recorded by a 35-millimeter instrumentation camera.

The operation of the T/F CAS consists of a series of timed events that are sequentially generated by the participating T/F CAS equipments. The quality of the performance of the T/F CAS equipments is dependent on the precision of the timing of the generation and detection of these events. Therefore, a primary function of the instrumentation is to provide a high-resolution time base for recording the time of occurrence and to identify the events as they are generated or detected by the associated T/F CAS. Other functions of the instrumentation are to record associated data that are related to the timing of the events. The instrumentation also calculates selected parameters from the event times and displays them in real time so that the T/F CAS and instrumentation can be monitored for proper operation.

The instrumentation receives the 5-MHz reference frequency generated by the CAS and doubles it to 10 MHz to obtain timing increments of 0.1 microsecond. The times of occurrence of events are measured by this time base and are recorded with identifying data of type of event and the epoch number and slot number in which the event occurred. The timed events which are recorded by the ATA instrumentation are listed below, along with the type of time slot in which they occur.

Event	Time Slot
Little Tee (LT or t_o)	Every Slot
Range Pulse Trans. (RPXD)	Own Slot
Altitude Pulse Trans. (ALXD)	Own Slot
Fine Synch. Recd., Gud (TSGD)	Own Slot
Fine Synch. Recd., Air (TSAR)	Own Slot
BUM Warn Recd. (THWRD)	Own Slot
BUM Maneuv. Recd. (THMRD)	Own Slot
Range Pulse Recd. (RPRD)	Intruder Slots
Altitude Pulse Recd. (ALRD)	Intruder Slots
Fine Synch. Trans. (TSXD)	Intruder Slots
BUM Warn Trans. (THWXD)	Intruder Slots
BUM Maneuv. Trans. (THMXD)	Intruder Slots
Epoch Start Trans. (TPXD)	Lead Slot (0000)
Epoch Start Recd., Gnd (BTRD)	Lead Slot (0000)
Epoch Start Recd., Air (TPRD)	Lead Slot (0000)

Other data are recorded which are related to the equipment performance or are required to correlate the data with data collected from the other equipments.

Epoch Number - An epoch counter counts the number of epochs since the counter was reset. This number is recorded with each lead slot.

Status Bits - There were 54 bits provided in the original design to record information on aircraft status, CAS status, equipment modifications, etc. In this test program one bit was used for the strut switch position and 12 bits were used to record the number of active slots when the traffic-simulation test was run. These bits are recorded in each slot, including the lead slot.

Slot Number - The slot number of each active slot is recorded.

Bi-Phase Data - The hierarchy and synchronization request address transmitted in, or read from, the range pulse is recorded with each active slot.

Digital Altitude - The coded altitude is recorded in the same bit pattern as received from the encoding altimeter.

Own-Altitude Rate - The altitude rate of own aircraft is recorded in the coded form as received from the CAS.

Range Rate - The range rate of the intruder is digitized by the analog-to-digital (A/D) converter and recorded with each active intruder slot.

There is provision for real-time display of selected data from two intruder slots and from own slot. By means of thumb-wheel digi-switches, any two intruder slots can be selected for real-time display. The information displayed is the slot number, the range to the intruder, and the altitude of the intruder. The slot number and the altitude being transmitted are displayed for own CAS. The number in the epoch counter is also displayed.

The individual items of data are collected in the memory and then are transferred to tape in the sequence and format shown in Figure 2-5. The data shown for Lead Time Slot are recorded at the beginning of each epoch. The events, with the times of occurrence, that are recorded for each lead slot are: (1) air epoch start transmitted; and (2) air or ground epoch start received. Other data recorded are: (1) slot number; (2) epoch number; (3) strut switch position, which indicates whether the altitude pulse is or is not being transmitted; and (4) a count of the active slots during the last epoch.

Following the Lead Time Slot record will be records for as many active time slots as occur during the epoch. The timed events recorded in each active slot are: (1) t_o time; (2) range pulse time; (3) altitude pulse time; (4) fine-synchronization-reply time; and (5) if in back-up mode, the times of the warning pulse and the maneuver pulse. Also recorded with the timed events are data on whether the pulses were transmitted or were received. Other data recorded are: (1) identification of own slot; (2) if the intruder time slot is real-time displayed, identification as intruder #1 or intruder #2; (3) strut switch; (4) the transmitted

or received bi-phase data in the range pulse; (5) the altitude code; (6) own-aircraft altitude rate; (7) count of active time slots; and (8) range rate.

If any event occurs improperly, the event will be recorded but the regular sequence of events that should be associated with it will not occur. This causes a short record to be recorded that can be used to determine what the improper event was.

The recorded tape is computer-processed by using a program that decodes the recorded times into the measured ranges, range rates, altitudes, altitude differences, etc., that are required to evaluate the performance of the TF/CAS. The processed data are sorted by time slot and printed for each epoch in which activity occurred in the time slot.

2.6.2 McDonnell Douglas Instrumentation - Full System

The instrumentation designed and built by McDonnell Douglas for use with the EROS II Model 2000 full system differs from the ATA instrumentation in that it is capable of collecting performance data on only one intruder slot per epoch.

This instrumentation processes the transmitted and received data and displays the data in real time on the panel shown in Figure 2-6. The displays are LED seven-segment displays or LED lights. The data items displayed are as follows:

Epoch Number - This is a four-digit number that is the count of the epochs since the counter was reset. A push-button switch is provided to reset the counter to zero so that the epoch counts of all participating systems will be in step.

Own Message Slot (OMS)

OMS Slot Number - This is a four-digit number that displays the number of the time slot in which the CAS transmitted each time the CAS transmits.

Xmit ALT X100 FT - This is a three-digit display of the altitude, in hundreds of feet, that the CAS transmitted. The number is the value the instrumentation decoded from the spacing of the range pulse and altitude pulse.

Hier - This is a two-digit number that displays the hierarchy the instrumentation decoded from the bi-phase modulation transmitted by the CAS.

Sync Address - This is a four-digit number that displays the fine-synchronization request address the instrumentation decoded from the bi-phase modulation transmitted by the CAS.

MSB	0
	0
	0
	0
	0
	0

(ACTI

				0	0		0	0	INT 1			0	INT 1			MSB	0	LSB	0	0	0	INT 1			0	0	0		0	B1
				0	0		0	0	INT 2			0	INT 2				0		0	0	0	INT 2			0	0	SF3		0	B2
				0	MSB		0	RCD	B			0	B				0		0	0	XMT	0			0	0	SF2		D4	B4
				0			0	0	0			RCD	0				0		0	0	0	A			0	0	SF1		A1	C1
				0			0	XMT	MSB			0	MSB				0		0	0	AIR	MSB			0	0	SIGN		A2	C2
				0		LSB	0	0			LSB	XMT			LSB		0		0	0	GND			LSB	0	0	MSB	LSB	A4	C4
t_o TIME					RANGE RATE		CAS STAT.	BUM MANEUVER TIME				BUM WARNING TIME				CAS STATUS (ACTIVE SLOT COUNT)					FINE SYNC. TIME				OWN ALT. RATE				ALT. CODE	
SECOND ACTIVE TIME-SLOT				FIRST ACT																										

Figure 2-5. DIGITAL DAT

CAS STATUS (ACTIVE SLOT COUNT)					MANUAL CONTROL		EPOCH NUMBER				STRUT SWITCH		SLOT NUMBER				T_o/T_o' RCD. TIME				t_o TIME				LEAD CODE			
MSB	0	LSB	0	0	0	0	0	0	0	0	0	0	0	0	0	0	T_o' RCD	0			0	0			1	1	1	1
	0		0	0	0	0	0	0	0	0	0	0	0	0	0	0	T_o' RCD	0			T_o' INT	0			0	DIU #5	0	0
	0		0	0	0	0	8000	800	80	8	0	0	0	800	80	8	0	B			0	0			0	#4	0	0
	0		0	0	0	0	4000	400	40	4	0	0	0	400	40	4	0	0			T_o' XMT	A			1	#3	0	0
	0		0	0	0	0	2000	200	20	2	0	0	0	200	20	2	0	MSB			0	MSB			0	#2	0	0
	0		0	0	0	0	1000	100	10	1	0	AIR	1000	100	10	1	0			LSB	0			LSB	0	#1	0	0

LEAD TIME-SLOT (0000)

	OWN ALT. RATE				ALT. CODE		ALTITUDE TIME				BI-PHASE DATA					SYNC. ADDER		HIERARCHY		STRUT SWITCH		SLOT NUMBER				RANGE TIME				t_o TIME			
	0	0	0		0	B1	RCD XMT	INT 1									LSB		LSB	0	0	0	0	0	0	0	INT 1			0	INT 1		
	0	0	SF3		0	B2		INT 2												0	0	0	0	0	0	0	INT 2			0	INT 2		
	0	0	SF2		D4	B4		B												0	0	0	800	80	8	0	B			0	0		
	0	0	SF1		A1	C1		0												0	0	OWN	400	40	4	1	0			0	A		
	0	0	SIGN		A2	C2		MSB										MSB		0	0	0	200	20	2	1	MSB			0	MSB		
SB	0	0	MSB	LSB	A4	C4				LSB						EVEN		ODD	MSB	0	AIR	1000	100	10	1	0			LSB	0			LSB

FIRST ACTIVE TIME-SLOT

re 2-5. DIGITAL DATA TAPE FORMAT

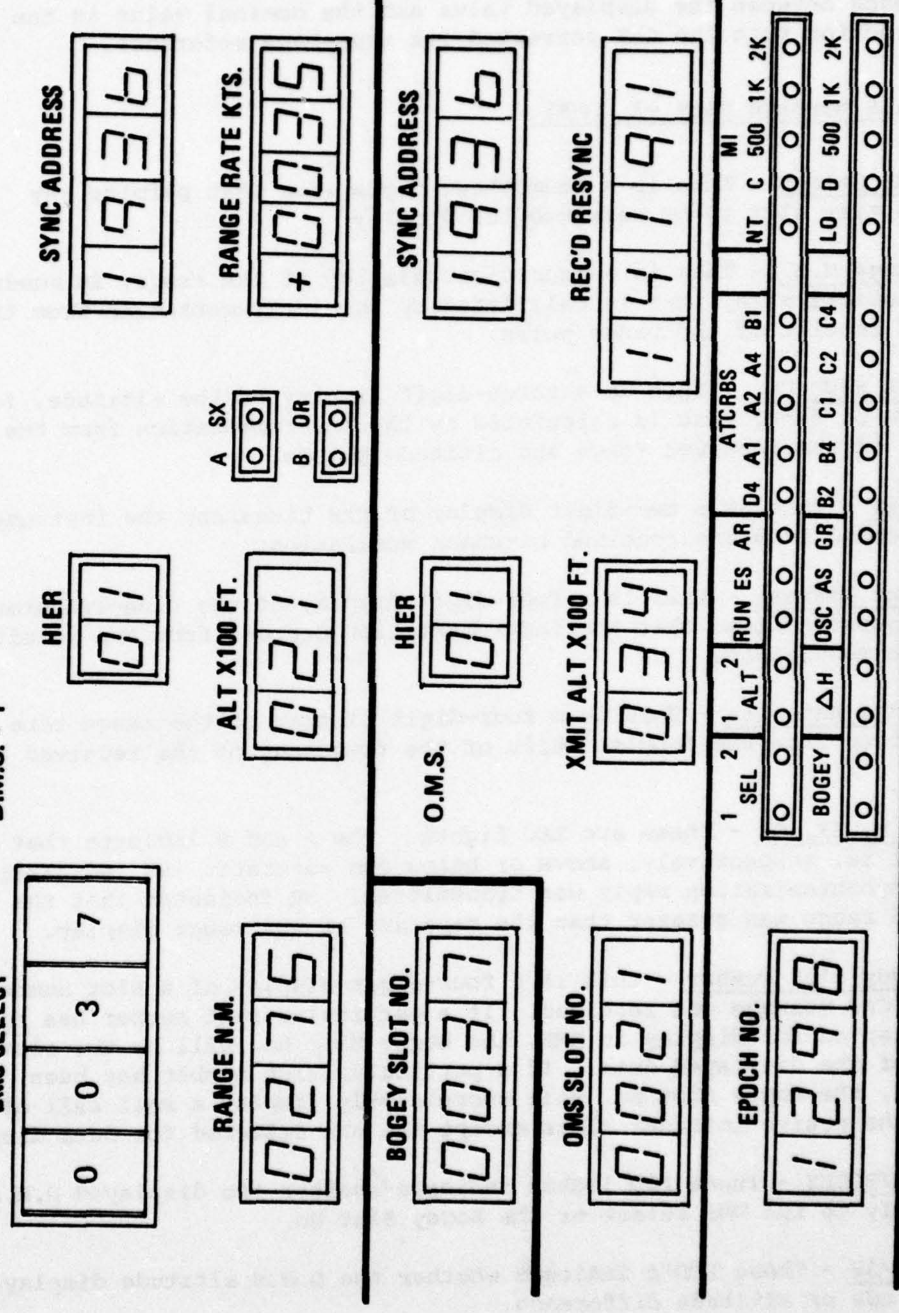


Figure 2-6. MDEC INSTRUMENTATION FOR EROS II MODEL 2000

Rec'd Resync - This is a five-digit number that displays the new fine-synchronization time as calculated from the time of receipt of a fine-synchronization triad. The nominal value is 1419.2 microseconds. The difference between the displayed value and the nominal value is the amount and direction that the CAS corrected its time-base reference.

Data Message Slot -1 (DMS)

DMS Select - This is a thumbwheel digiswitch that permits any desired time slot to be selected for display.

Range N.M. - This is a four-digit display of the range, in hundredths of a nautical mile, that is calculated by the instrumentation from the time of receipt of the range pulse.

Alt x100 Ft. - This is a three-digit display of the altitude, in hundreds of feet, that is calculated by the instrumentation from the spacing of the received range and altitude pulses.

Hier - This is a two-digit display of the hierarchy the instrumentation decoded from the received bi-phase modulation.

Sync Address - This is a four-digit display of the fine-synchronization request address that the instrumentation decoded from the received bi-phase modulation.

Range Rate KTs - This is a four-digit display of the range rate the CAS derived from the doppler shift of the frequency of the received range pulse.

A, B, SX, OR - These are LED lights. The A and B indicate that the aircraft is, respectively, above or below own aircraft. SX indicates that a fine-synchronization reply was transmitted. OR indicates that the measured range was greater than the capacity of the range display.

Bogey Slot Number - This is a four-digit display of a slot number in which a CAS message was received. If a particular slot number has not been selected for display in DMS, the Bogey Slot No. will be the slot number of the displayed data. If a particular slot number has been selected, the Bogey Slot No. will successively display a roll call of all of the active intruder slots except the one selected for data display.

SEL/BOGEY - These LED lights indicate whether the displayed D.M.S. data apply to the DMS Select or the Bogey Slot No.

ALT/ΔH - These LED's indicate whether the D.M.S altitude displayed is altitude or altitude difference.

RUN/OSC - These LED's are malfunction indicators.

ES - This LED indicates that an epoch start was decoded.

AS - This LED indicates that the CAS is switching between upper and lower antennas.

AR/GR - These LED's identify the source of the REC'D RESYNC as from another aircraft or from a ground station.

ATCRBS - These 10 LED's display the code of the altitude received from the encoding altimeter.

MI - These 10 LED's duplicate the display on the Maneuver Indicator; no-turn, climb, level off, dive, limit climb/dive to 500/1000/2000 feet per minute.

2.6.3 McDonnell Douglas Instrumentation - MICRO CAS

The Model 2002 MICRO CAS is much simpler than the full system, and this simplification is reflected in the instrumentation. This display panel is shown in Figure 2-7.

The lower box in the figure is the front panel of a simple set of instrumentation that can be used as part of a MICRO CAS installation.

Data Slot - This is a thumbwheel digiswitch that permits selection of the time slot to be displayed.

Range - N.M. - This is a three-digit display of range to the intruder in tenths of nautical miles.

Alt. Diff - FT/Slot No. - This is a four-digit display of either the altitude difference between intruder and own aircraft or a slot number.

Own Slot/ALT./Srch Slot - This is a three-position selector switch. When it is in the "Own Slot" position, the slot number that the MICRO CAS is using is displayed. When it is in the "ALT" position, the slot number displayed is the one selected on the thumbwheel digiswitch and the information displayed is range and altitude difference. One of the "Above You" or "Below You" lights will illuminate to indicate the direction of the altitude difference. When it is in the "Search Slot" position, the range and slot number of all active slots are displayed in a sequential roll call.

The upper box of the figure shows the display panel of instrumentation intended only for test purposes.

Epoch Number - This is a three-digit display of epoch count. The reset button is to the right of the display window.

ATCRBS - The middle window contains nine LED's that display the altitude code received from the encoding altimeter.

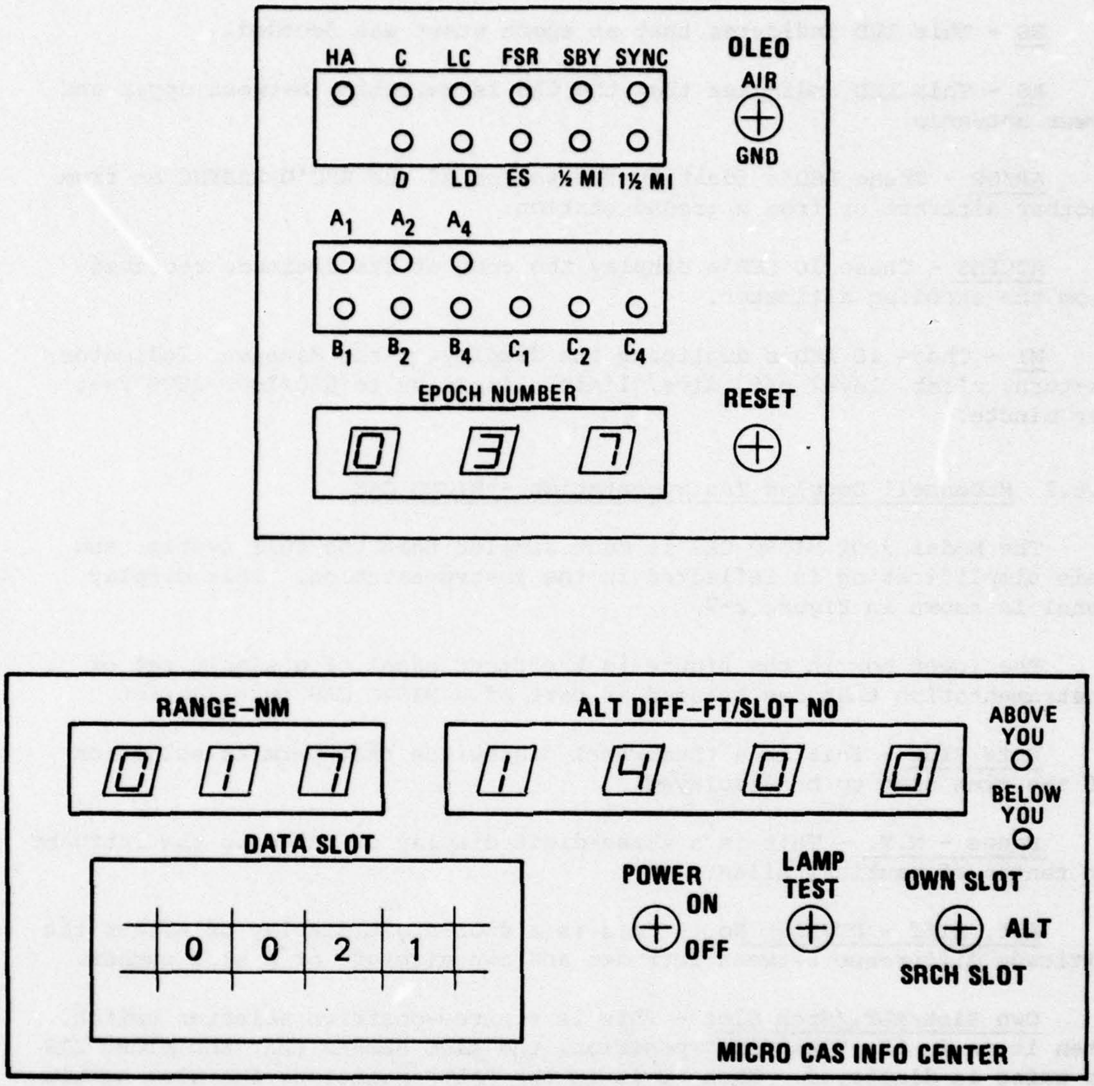


Figure 2-7. MDEC INSTRUMENTATION FOR EROS II MODEL 2002, MICRO CAS

Upper Window

HA, C, LC, D, LD - The five LED's in the left half of the window duplicate the information displayed on the maneuver indicator: hold altitude (HA), climb (C), limit climb (LC), dive (D), and limit dive (LD).

FSR, ES - These LED's indicate each epoch in which fine synchronization is received (FSR) and in which an epoch start is decoded (ES).

SBY, SYNCH - These two LED's indicate the status of operation. When the CAS is synchronized and transmitting normally, the "Sync" light will be on. When the CAS is not synchronized, the standby light (SBY) will be on, It will also be on if the CAS is operating in the ground mode, i.e., when not transmitting the altitude pulse.

½ MI, 1½ MI - These LED's indicate that the CAS is operating in the terminal-area mode (½ mile) or en route mode (1½ mile).

Oleo - This is a two-position switch that simulates the oleo strut switch of a normal installation. The "AIR" position enables and the "GND" position inhibits transmission of the altitude pulse.

2.6.4 Video Recorder

The detected video from each MICRO CAS receiver was recorded on a Sony Model AV 3600 video recorder. These recordings provide a permanent record of the transmitted and received signals that can be examined at leisure for the effects of multipath, the presence of interference, the timing of transmission, etc.

The recorder was powered by an inverter in the aircraft that provided 110 volts at approximately 60 Hz. A more accurate frequency for the power source would have made the reading of the recorded tape easier. An operational amplifier was used as a signal mixer to mix the detected video with the sync pulses generated by the recorder. The recorded tape is read in the pause mode, and the sync pulses from the recorder are needed on the tape to provide a stable reference point in the recording to synchronize the sweep start time of the oscilloscope.

2.6.5 Tracking Radar

The metric data of range, range rate, and altitude difference between aircraft were obtained from Eastern Test Range radars tracking C-band beacons installed in the aircraft. The C-band beacons were calibrated individually, and each had a separate code. Each aircraft was continuously tracked by its assigned radar.

The tracking data from the radars were processed by an on-line computer to generate and display in real time the position of each aircraft and the range, range rate, and altitude difference between the aircraft. These displays were used for controlling the aircraft so that they could be positioned and vectored to execute the desired encounter patterns.

The displays were also used for range safety and to aid the flight crews in obtaining visual acquisition of the other aircraft.

The tracking data from the radars were also tape-recorded. These data were smoothed and merged by computer to generate data tapes for aircraft pairs. These data, generated at 0.1-second intervals, consist of latitude, longitude, and altitude of each aircraft, and range, range rate, and altitude difference between the aircraft. Latitude and longitude were in degrees with a resolution of four decimal places. Altitude, altitude difference, and range were in feet with a resolution of two decimal places. Range rate was in feet per second with a resolution of two decimal places. These latter resolutions are considerably in excess of the actual accuracy of the data; however, evaluation of the data indicated the accuracy to be better than the requested 50 feet, which is adequate for evaluation of the T/F CAS.

The Eastern Test Range generates and distributes by wire network a precise Range Time for correlating data from the widely dispersed facilities. The radar data were recorded against this Range Time base. The T/F CAS test data, which were recorded by epoch and time slot, were synchronized to the radar data by synchronizing the epochs to start within five microseconds of the minute and multiples of three seconds with reference to the Range Time. The timing of epochs was controlled by the ground station, which had a cesium-beam oscillator to provide the reference frequency.

2.7 TEST-BED AIRCRAFT

A total of five Air Force aircraft of three types were used in the flight-test program. One C-131B aircraft was supplied by ADTC at Eglin AFB, one C-131B aircraft and one NKC-135 aircraft were supplied by Rome Air Development Center, and two F-106A aircraft were supplied by the 49th Fighter Interceptor Squadron based at Griffis AFB. Hereafter the aircraft are referred to as C-131, KC-135, or F-106.

The C-131 type aircraft were the principal test beds. These aircraft are configured as general-purpose test beds to facilitate the installation of test hardware. They have rails for mounting standardized test racks running almost the full length of the cargo compartment. They also have power and communication panels at about 10-foot intervals. Power for the test projects is supplied by auxiliary-power pods. A special effort has been made to suppress on-board generated noise that could interfere with the test projects.

Each of the C-131 aircraft had two T/F CAS equipments installed. The ADTC aircraft had a MICRO CAS installed in the forward area and a FULL CAS installed in the aft area. The MICRO CAS had the McDonnell Douglas instrumentation and a video recorder. The FULL CAS had McDonnell Douglas instrumentation. The MICRO CAS had a single quarter-wave stub antenna mounted on top of the fuselage. The FULL CAS had two quarter-wave antennas, installed top and bottom of the fuselage, that were used alternately.

The installation in the RADC aircraft was the same for the MICRO CAS, and the installation of the FULL CAS differed only in that the instrumentation was ATA instead of McDonnell Douglas.

The KC-135 aircraft was also configured as a general-purpose test bed. A FULL CAS was installed with ATA instrumentation in the forward area of the cargo compartment. Two antennas were installed, one on top and one on the bottom of the aircraft. The KC-135 was a high-priority aircraft that had to be released as soon as possible; therefore, it was used only for the test flights that required additional aircraft or required the performance capability it provided. These tests were conducted early in the program, and the aircraft was released.

The F-106 aircraft were standard operational interceptors. They also were high-priority aircraft that had to be released as soon as possible. It was necessary that the T/F CAS installation be accomplished in such a manner that the aircraft could be restored to operational configuration quickly. The CAS and its McDonnell Douglas instrumentation were mounted on a pallet that was installed in the avionics bay. The installation was virtually self-contained in that it interfaced with the aircraft only for antenna mounting, power, and an epoch counter reset button in the cockpit. The antennas were mounted about 30 degrees off the vertical axis because normal installation would have required unacceptably extensive modification to the aircraft to accommodate the antenna cable run. The F-106 aircraft were used for the supersonic tests, and one of them was used for the synchronization test.

2.8 DESCRIPTION OF THE DATA COLLECTED

The data recorded during the various missions are identified in Table 2-2. The various tests required that different types of data be collected. The unusable data indicated in the table were digital tape data that could not be processed by the computer. Many of the data could be extracted from these tapes by a laborious process of tape dumps. Fortunately, the data on these tapes were not critical to the overall analysis.

A test code has been associated with each mission flown during the flight test program. These test codes are described below.

<u>Test Code A</u> - The supersonic mission required photo panel data from the F-106 aircraft, ground-station digital tape data, and radar metric tracking data. The Air Force desire to return the F-106 aircraft to the Aerospace Defense Command made it extremely important that the quick-look data analysis of this mission be performed as rapidly as possible. The photo panel film from this mission was developed and reviewed within 48 hours after the completion of the mission. The quick-look analysis revealed that the film was readable - although a great deal of effort would be required to extract the data. The poor background lighting made the film appear underexposed. The ground-station magnetic-tape data were processed in two separate computer runs. The first computer run processed the data for the

Table 2-2. Summary of Data Collected During T/F CAS Test Program

Test Code	ETR Test No.	Mission No.*	Date	Description	C-131 37819 (819) Digital Tape-CAU	C-131 37819 (819) Photo Panel-MICRO	C-131 37819 (819) Video Tape-MICRO	C-131 37804 (804) Photo Panel-CAU	C-131 37804 (804) Photo Panel-MICRO	C-131 37804 (804) Video Tape-MICRO	KC-135 53125 (125) Digital Tape-CAU KC-135 #125	F-106 90075 (075) Photo Panel-CAU F106 #075	F-106 90069 (069) Photo Panel-CAU F106 #069	Ground Data Digital Tape-T&E	Ground Data Photo Panel-MICRO	Ground Data Video Tape-MICRO	Ground Data Metric Tracking	Voice Recording
A	4893	9	3/7/73	Supersonic								x	x	x			x	x
B	3144	11, 12	3/6/73	Synchronization	+				x	x	+	x		+	x	x		x
C	4765	14	3/8/73	Multiple Aircraft	x	x	x	x	x	x	x			x				x
D	5719	8, 10	3/14/73	3-Aircraft & BUM	x	x	x	x	x	x	x			x			x	x
E	9629	13	3/27/73	Traffic Pattern	x	x		x	x	x				x			x	x
F	5954	1	3/16/73	2-Aircraft	x	x	x	x	x	x				x			x	x
G	9386	2	3/20/73	2-Aircraft	x	x	x		x	x				x			x	x
J	9715	5, (6)	3/26/73	2-Aircraft	x	x	x	x	x	x				x			x	x
K	9561	3, 6	3/28/73	2-Aircraft	x	x		x	x	x				+			x	x
L	9224	7, 4	3/22/73	2-Aircraft	x	x		x	x					x			x	x

* Mission Numbers used in the Test Plan

+ Data Not Useable
x Data Recorded

first set of encounters, and these data were available within two days after the test. The second computer run for the second set of encounters was available about a week after the mission was flown. The availability of the second set of data was delayed by problems with the data-reduction program. The CAS systems on the F-106's were intentionally forced to operate in back-up mode during a portion of the test. The ground station was led to believe that many slots were active, and data were recorded on all of these active slots on the digital tape. As a result, the data-reduction program was unable to process the digital-data tape directly. The digital-data tape had to be analyzed in four segments, and this resulted in a week's delay in processing the digital data.

Test Code B - The synchronization test was designed to determine the ability of the MICRO CAS units to detect fine- and coarse-synchronization triads. One MICRO CAS was operated at the Cape Kennedy skid strip, and a second was operated in a low-flying C131. Three FULL CAS units were airborne and were providing both coarse- and fine-synchronization support to the MICRO CAS's. The ability of the MICRO CAS's to recognize both coarse and fine synchronization was recorded from the photo panels, and the raw signals (i.e., the received triads) were recorded on video tape. Because the video tapes were a primary source of data during the mission, they were reviewed immediately after the test to verify that the video recording systems were working properly.

During this test, an attempt was made to record data from the FULL CAS units, but only the photo panel data from the CAS in the F-106 were recorded properly. The remainder of the FULL CAS data was placed on magnetic tape, but the digital data tapes could not be read because the tapes were new and had not been degaussed. Fortunately, the digital tape data were not essential to this mission. However, the quick-look data-analysis procedure prevented this problem from reoccurring on ensuing missions. There was no requirement for metric tracking data during this mission. The MICRO CAS and the F-106's FULL CAS photo panel data were processed at the same time as the data from the supersonic mission.

Test Code C - The multiple-aircraft tests demonstrated the ability of the FULL and MICRO CAS's to operate in a simulated dense aircraft environment. During this test, jamming signals were used to force the CAS units out of the message slots they were using and into new slots that were unoccupied. This process was repeated many times, and the data instrumentation was used to record the slot changes. The video tape recorders were used to provide a permanent record of the received jamming signals. There was no requirement for metric tracking during this test. The quick-look analysis consisted of analyzing the digital data tapes and reviewing the photo panel film data. Because of the number of slots used by the CAS equipments during this test, and the fact that the digital tapes had to be analyzed as 10 separate data segments, about 10 days were required to complete the analysis of the digital tapes. Because of the involved procedures for developing the photo panel film and because no problems were encountered with the photo panel data from tests A & B, the photo panel film was not developed immediately. Instead, the film was held for a week (to allow time for other missions to be completed), and then it was sent to the Kodak plant along with the film data from two other missions. There were no problems with the photo panel film for this mission.

Test Code D - This mission combined the three-aircraft encounters and the back-up mode tests into one flight. Complete photo panel, digital magnetic tape, video tape, and metric data were collected. The quick-look analysis indicated that the digital data and the photo panel data were recorded properly. The metric tracking data were recorded properly for all but two of the three-aircraft encounters. However, the quick-look analysis indicated that a sufficient quantity of usable metric tracking data were collected and that there was no need to re-fly the two three-aircraft encounters.

Test Codes E-L - The remaining tests consisted of the two-aircraft encounters and the traffic-pattern test. As noted in Table 2-2, data were collected from all of the various instrumentation sources in all but a few cases. The original test plan did not require video tape data during missions 3 and 13 (tests K and E); thus the lack of video tape data from aircraft number 819 is not considered critical. No photo panel data were recorded during mission 2 (test G), because of the configuration of the equipment on aircraft number 804. The primary purpose of this test was to collect data from the MICRO CAS units during combined vertical/horizontal encounters. It was necessary to provide true-altitude encoding data to the MICRO CAS's, and this made it impossible to provide meaningful altitude data to the full CAS units. Therefore, instead of collecting still more FULL-CAS data for aircraft in simulated level flight, it was decided to forego collecting photo panel data from the full CAS in aircraft number 804. Video tape data recording was planned for missions 4 and 7 (test L) in the test planning document, but no data were recorded because of a last-minute change in missions. Mission 3 was originally scheduled for 22 March, but a low cloud layer forced the postponement of mission 3 and the substitution of missions 7 and 4. Because mission 3 did not require video tape data, there were no tapes aboard the aircraft during missions 7 and 4.

The quick-look analysis of the digital tape data indicated that all desired data were collected during all missions except mission 3/6 (test K). During this mission the ground-station digital-data tape proved to be unreadable due to excessive parity errors. There was no explanation for these parity errors, and it was decided that the lack of ground-station data was not sufficiently critical to require repeating the mission. The remainder of the data for all of the two-aircraft-encounter and traffic-pattern tests were recorded properly.

2.9 QUICK-LOOK DATA ANALYSIS

The test program included a provision for a quick-look data analysis to verify that usable data were recorded during the missions. The quick-look analysis was applied to the primary data, which consisted of the photo panel data, the digital tape recording data, and the metric tracking data. The video tapes and voice tapes were considered to be supporting data that would be used at a later time to resolve any problems not adequately handled by the primary data recording. Therefore, they were not treated in the quick-look analysis.

The photo panel data were recorded on super 8 film from the McDonnell Douglas-supplied photo panels. Figures 2-6 and 2-7 indicated the data available on the model 2000 and the model 2002 (MICRO) CAS instrumentation panels. A movie camera was triggered each epoch (i.e., once every 3 seconds) to record the data displayed on the panels. Because of the low level of ambient light and the red LED displays, a very-high-speed color film was used (Ektachrome 160). There was concern that the film might not provide sufficient contrast, that the camera might not be triggered properly, and that unknown problems might arise to make the film unusable. Therefore, a quick-look review of the film data was instituted. The quick-look review entailed developing the film and reviewing it for clarity and for general agreement with the tracking data. Because a very special type of film was used, it was necessary to have the developing done by Kodak. There was a requirement to have the film developed within a few days after a mission; therefore, the film was sent to the Rockville, Maryland, Kodak facility via the airlines' small-parcel delivery system. ARINC Research personnel at the company offices in Maryland picked up the film and reviewed it. The results of this review were telephoned to the project team in Florida.

The metric tracking data were provided by the Eastern Test Range (ETR). The data consisted of a printout and 7-track magnetic tape containing the following:

1. Time
2. Latitude of aircraft no. 1
3. Longitude of aircraft no. 1
4. Altitude of aircraft no. 1
5. Latitude of aircraft no. 2
6. Longitude of aircraft no. 2
7. Altitude of aircraft no. 2
8. Slant range between aircraft
9. Range rate between aircraft
10. Altitude separation of aircraft

The data were recorded at 0.1-second intervals. Arrangements were made with ETR to have the metric-tracking-data printouts and tapes available within 24 hours after a test. The printouts were used to provide a coarse comparison between the CAS and the radar's range, range rate, and altitude differences between aircraft.

The CAS data that were recorded on magnetic digital tape were processed at the ETR computer facility. The computer processing was required to verify that the data tapes were readable and to provide a printout of the data format that could be reviewed conveniently. The magnetic tape data were recorded on instrumentation tape recorders in a non-laboratory environment. Therefore, there was concern about the quality (i.e., readability) of the recorded data. The quick-look analysis of the digital data tapes consisted of using an available tape-data reduction program (program TB125) to verify the readability of the raw data tapes, to provide a printout of the data, and to provide an output data tape that could be used in the later, more detailed data analysis. The printouts were reviewed and compared with the photo panel and metric tracking data to verify that the proper data were recorded.

2.10 DESCRIPTION OF THE CAS DATA BASE

A magnetic-disk data file was developed for all missions during which metric data were recorded. The file contained data from the following sources:

- The metric data tapes
- The ATA instrumentation data tapes
- The MICRO CAS photo panel data
- The FULL CAS photo panel data

The MICRO and FULL CAS data recorded from the McDonnell Douglas photo panels were keypunched onto computer cards to facilitate the processing of these data. Table 2-3 summarizes the data contained on the disk file. A record contains data from all CAS systems that were active during that epoch, and there is a separate record for each epoch of test data. The record numbers were used to access various portions of the data base.

The layout of the data-base records is shown in Figure 2-8. The Test Code and Epoch identify the record and appear only once. The remainder of the record is a matrix that permits the recording of data on up to 6 CAS systems. In actuality, no test requiring radar metric tracking involved more than five instrumented CAS units at one time, so that the vertical columns in the matrix could be permanently assigned to the five systems. Table 2-4 gives the assignments of system numbers to the CAS units for the various tests. As a result of the format of the data base and the assignment of the system numbers, many portions of the disk file were not used. For example, no data were entered in listen data block (1.1), because a CAS unit does not listen to its own transmissions.

Table 2-3. CAS DATA BASE					
Record Numbers		Epoch Numbers		Test Code	Data
Start	End	Start	End		
1	438	203	640	A	Supersonic - synchronized
439	546	4418	4584	A	Supersonic - BUM
547	617	4650	4721	A	High subsonic - synchronized
618	926	389	1213	D	3 A/C E-2 and E-3 in formation
927	1314	1325	2037	D	3 A/C E-1 and E-2 in formation
1315	1552	2557	3126	D	BUM
1553	2174	381	2066	F	2 A/C H~2000' ΔH~500'
2175	2843	2248	3796	F	2 A/C H~2000' ΔH~1000'
2844	3816	36	2379	G	2 A/C H~10000' ΔH~ 500'
3817	4653	2533	3746	G	2 A/C H~10000' ΔH~↘↗500'
4654	5122	184	1500	L	2 A/C H~10000' ΔH~500'
5123	5459	1700	2959	L	2 A/C H~10000' ΔH~1000'
5460	5959	3115	4421	L	2 A/C H~10000' ΔH~500' radar altimeter
5960	6488	502	1847	J	2 A/C H~10000' ΔH~ ↘↗500'
6489	6940	2287	3469	J	2 A/C H~2000' ΔH~ ↘↗500'
6941	7149	3724	4367	J	2 A/C H~2000' ΔH~500' radar altimeter
7150	7806	132	1845	E	Traffic Patterns
7807	8264	198	1503	K	2 A/C H~2000' ΔH~↘500'
8265	8507	1752	2431	K	2 A/C H~2000' ΔH~↗500'
8508	8694	2540	2995	K	2 A/C H~2000' ΔH~500' radar altimeter

Table 2-4. ASSIGNMENT OF CAS SYSTEM NUMBERS		
Test Code(s)	System Numbers	CAS Units
A	4	CAU on F-106 #075
	3	CAU on F-106 #069
	9	Ground Station
D	2	CAU on C-131 #819
	8	MICRO on C-131 #819
	3 or 7	CAU or MICRO on C-131 #804 depending on which system was active for the given epoch
	1	CAU on KC-135 #125
	9	Ground Station
F,G,L, J,E,K	2	CAU on C-131 #819
	8	MICRO on C-131 #819
	1	CAU on C-131 #804
	7	MICRO on C-131 #804
	9	Ground Station

CAS Data Record:

Test Code	Epoch	OMS Data System #1	Listen Data System #1 (1,1)	Listen Data System #2 (1,2)	Listen Data System #3 (1,3)	Listen Data System #4 (1,4)	Listen Data System #5 (1,5)
		OMS Data System #2	" (2,1)	" (2,2)	" (2,3)	" (2,4)	" (2,5)
		OMS Data System #3	" (3,1)	" (3,2)	" (3,3)	" (3,4)	" (3,5)
		OMS Data System #4	" (4,1)	" (4,2)	" (4,3)	" (4,4)	" (4,5)
		Not Used	" (5,1)	" (5,2)	" (5,3)	" (5,4)	" (5,5)
		OMS Data System #5	" (6,1)	" (6,2)	" (6,3)	" (6,4)	" (6,5)

Total Record Length 1410 Bytes

OMS Data Block:

Slot No.	CAS ID	ATC-RBS	Transmitted Altitude	Transmitted Bi-Phase	Received Sync Triad Time	Back-up Mode Pulse Time	Bum Pulse Code

24 Bytes

Listen Data Block:

CAS ID	True Range	True Range Rate	True Altitude Separation	CAS Range	CAS Range Rate	CAS Altitude Separation	CAS Threat	Received Bi-Phase	Back-up Mode Pulse Time	Bum Pulse Code	Transmit Sync Triad Time

42 Bytes

OMS Data - Data generated during a CAS own message slot (i.e., data associated with the transmission of a range and altitude pulse).

Listen Data - Data received by a CAS from an active (or transmitting) CAS.

Figure 2-8. CAS DATA RECORD LAYOUT

The data base was built by making a series of computer runs. First, the data base was initialized by defining a record for each epoch of interest for each mission having radar tracking. The initialization program specified the test code and the epoch number and reserved 1404 bytes (or data positions) for the CAS data. Next, the own-message-slot (OMS) data were entered into each of the records. The photo panel data (appearing on punched cards) and the ATA instrumentation data (contained on magnetic tapes generated by the TB125 data-reduction program) were inserted in the disk records. Control cards associated with the disk update programs specified the row in which the OMS data should be entered.

The next step in building the CAS data base was to enter the listen data. The listen data contain the one-way measurements made by the CAS systems during the various active slots during each epoch. Therefore, the listen data had to be aligned with the OMS data by comparing the slot number appearing in the OMS data block with the slot number associated with the listen data. The listen-data disk update programs compared the OMS and listen-data slot numbers to determine the proper row, and a control card specified the proper column for the block of listen data. The listen-data block does not contain the slot number, as the slot number for the OMS data block will apply to the entire row of data. Because the photo panel instrumentation permitted data to be recorded from only one CAS, the photo panel data generated only one block of listen data for each epoch. However, the ATA instrumentation permitted data to be recorded on many CAS's simultaneously; thus multiple blocks of listen data were entered in the column reserved for the system with this instrumentation (e.g., the FULL CAS on C-131 #819).

The final step in building the CAS data base was to insert the metric tracking data in the "true range", "true range rate", and "true altitude separation" data fields. The metric data were recorded at 0.1-second intervals; it was thus necessary to interpolate these data to obtain the true values corresponding to each active data slot.

The data blocks were configured to permit all the data generated by the ATA instrumentation to be recorded. However, the photo panel instrumentation was limited, and as a result the backup-mode data fields in both the OMS and listen-data blocks for the FULL CAS on C-131 #804 and the MICRO CAS's contained zeros.

The bi-phase and range-rate data fields did not apply to the MICRO CAS units, and these fields contained zeros. The CAS ID codes were assigned as follows:

CAS ID Code	CAS Equipment
1	FULL CAS - McDonnell Douglas S/N 1
2	FULL CAS - McDonnell Douglas S/N 2
3	FULL CAS - McDonnell Douglas S/N 3
4	FULL CAS - McDonnell Douglas S/N 3

(continued)

CAS ID Code	CAS Equipment
7	MICRO CAS - McDonnell Douglas S/N 3
8	MICRO CAS - McDonnell Douglas S/N 4
9	T&E Ground Station

Figure 2-9 shows a printout of a portion of the data in a data record for test code F, epoch 697. The figure shows the data for one epoch during a two-aircraft, 30-knot scissors maneuver for the mission flown on 16 March 1973. The FULL CAS on C-131 #819 is transmitting in slot 33, but none of the other airborne instrumentation systems is recording data on these transmissions (the other CAS units are, of course, listening to these transmissions and evaluating them for a potential threat). The MICRO CAS on C-131 #819 is transmitting in slot 5, and both the MICRO CAS and the FULL CAS on C-131 #804 are displaying data on these transmissions. The CAS ID codes 1 and 7 identify the FULL CAS and MICRO CAS on C-131 #804, respectively. The FULL CAS on C-131 #804 is transmitting in slot 25, and the FULL CAS and MICRO CAS on C-131 #819 were recording data on these transmissions. The MICRO CAS on C-131 #804 was transmitting in slot 2, and the FULL CAS on C-131 #819 was recording data on these transmissions. The threat-status numerical values represent a binary encoding of the threat status, and the values shown in Figure 2-9 indicate the following:

Threat Status Code	Interpretation
519	Limit descent to 500 FPM, no turn
33	Climb
17	Dive

Fields containing an asterisk (*) were data fields that were blank on the photo panels and have been identified with an asterisk to distinguish them from a numerical reading of zero.

Figure 2-9. TYPICAL CAS DATA RECORD

TEST CODE F EPOCH 697

SLOT 33 CAS-ID 2 ATCRBS 16 TRANS ALT 58 TRANS BI-P 0 1 2047 SYNC TIME 0.0

CAS ID	TRUE RANGE	T-R RATE	T-D ALT	CAS RANGE	CAS R-RATE	CAS D-ALT	THREAT STATUS	RECEIVED BI-P

SLOT 5 CAS-ID 8 ATCRBS 16

CAS ID	TRUE RANGE	T-R RATE	T-D ALT	CAS RANGE	CAS R-RATE	CAS D-ALT	THREAT STATUS	RECEIVED BI-P
1	127	21	-4529	110	-15	-4500	519	0 63 2047
7	127	21	-460	130	0	-400	33	0 0 0

SLOT 25 CAS-ID 1 ATCRBS 62 TRANS ALT 6200 TRANS BI-P 0 1 1928 SYNC TIME********

CAS ID	TRUE RANGE	T-R RATF	T-D ALT	CAS RANGE	CAS R-RATE	CAS D-ALT	THREAT STATUS	RECEIVED BI-P
2	127	21	200	124	57	150	0	0 2 1928
8	127	21	4529	130	0	4600	17	0 0 0

SLOT 2 CAS-ID 7 ATCRBS 21

CAS ID	TRUE RANGE	T-R RATE	T-D ALT	CAS RANGE	CAS R-RATE	CAS D-ALT	THREAT STATUS	RECEIVED BI-P
2	127	21	-3843	118	45	-3875	0	0 63 2047

CHAPTER THREE

ANALYSIS OF THE T/F CAS FLIGHT TEST DATA

3.1 OBJECTIVES

The data obtained from the flight-test program provide information on the overall performance of the Time/Frequency Collision Avoidance concept. These data were analyzed to determine the typical measurement accuracies (or inaccuracies) associated with the concept and to evaluate factors that could prevent the system from making any measurement at all. This chapter provides a detailed description of the analyses performed on the CAS data.

The analysis of the measurement accuracies of the T/F CAS concept was performed on the large volume of data collected from the two-aircraft-encounter missions. Only data for properly operating CAS equipments were considered in this analysis to obtain the best estimate of the true capability of the T/F CAS concept. The analysis of the system accuracies is complex and lengthy; hence, Section 3.2 provides the reader with a "roadmap" for the analyses in Section 3.3.

The remainder of Chapter Three provides the analysis of those aspects of the CAS concept that are prerequisites to the CAS ability to evaluate aircraft threats, and it details the flight tests of three special cases of T/F CAS operation. Factors that directly affect and are prerequisites to the ability of T/F CAS equipments to make measurements of aircraft range, range rate, and altitude are communications reliability, time-base synchronization, and resolution of time-slot co-occupancy conflicts. The special cases of T/F CAS operation that were evaluated in the present test program were three-aircraft encounters involving CAS equipment having different threat logic, supersonic encounters, and encounters involving two aircraft with CAS equipments operating in an alternate or back-up mode.

3.2 APPROACH TO THE ANALYSIS OF THE CAS MEASUREMENT ACCURACIES

The ultimate test of a collision-avoidance system is to determine how closely to the proper times the warnings and alarms are generated and to determine the probability of false and missed alarms. Unfortunately, an analysis providing this determination is not possible, because these factors are closely tied to the scenario in which the CAS must operate. Because there is no commonly accepted scenario against which a CAS must

be judged, the DoD CAS working group decided that the CAS evaluations should only provide the data from which one could evaluate the performance of a CAS concept once a scenario is specified. This report, therefore, provides the complete characterization of the measurement accuracies of the CAS concept in terms of "error models". As a guide to the application of the T/F CAS error models to any given encounter situation or scenario, an analytical procedure was developed and applied to three specific situations to evaluate the probability of warnings and alarms at various ranges or times prior to an encounter.

The error models (or probability functions) are developed and discussed in Section 3.3 to reflect any dependence of the measurement errors on test parameters (e.g., range, range rate, altitude, altitude separation). Therefore, it was necessary to perform a number of tests on the CAS error data to establish the basic characteristics of the error models. To determine the form of the error distributions (e.g., normal, exponential, Weibull) so as to expedite and make more rigorous the ensuring statistical analyses, a sample of data was evaluated in detail. Then the data were partitioned according to range, range rate, altitude, and altitude separation to permit a statistical analysis of variance to be performed. This analysis identified variations in the CAS measurement errors due to the test parameters that were statistically significant. Then a regression analysis was performed to predict the mean measurement errors based on those variations in the CAS errors that were significant from both a statistical and an engineering point of view. Most of the CAS measurement errors were not affected by the test parameters, and in these cases no regression analysis was required to predict the mean errors. Once the form of and the parameters for the error models were developed, the models were applied to the evaluation of CAS warning and alarm times, and possible simplifications in the application of these models were identified.

3.3 ACCURACY ANALYSES FROM TWO-AIRCRAFT-ENCOUNTER DATA

The flight-test data are analyzed here to determine engineering models of the range, range rate, and altitude-separation measurement accuracies of the T/F CAS concept. It was necessary to determine the statistical distributions of the data, derive appropriate parameters for these distributions, and determine statistically acceptable combinations of the various categories of data.

3.3.1 Qualitative Examination of a Single Encounter

The data generated by a 100-knot scissors maneuver were examined in detail to determine the types of errors and patterns that might occur between successive CAS measurements. Figure 3-1 (a-e) shows the differences between the metric and CAS measurements of range, range rate, and altitude separation for the following system combinations:

- FULL CAS on C-131 #819 listening to FULL CAS on C-131 #804

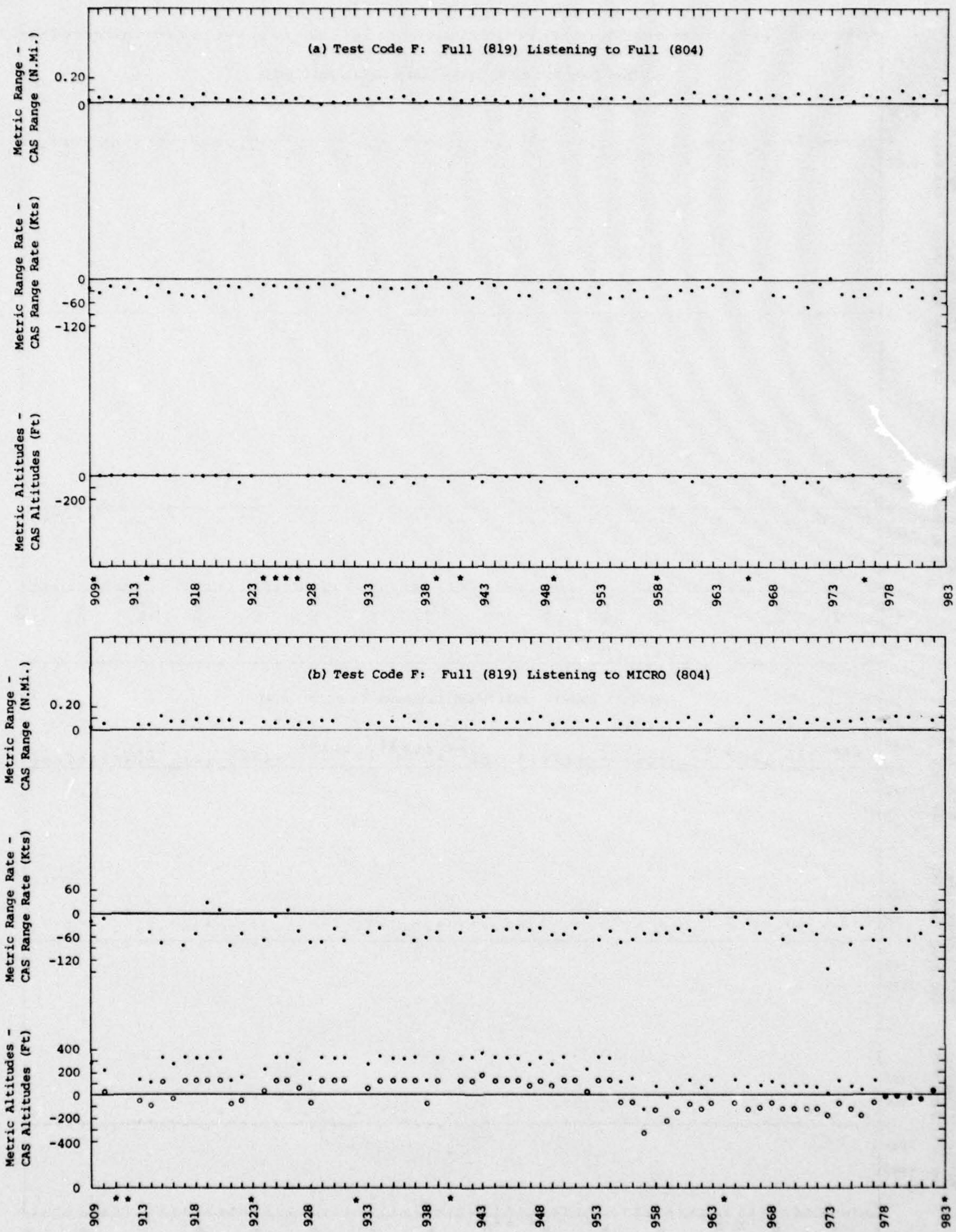
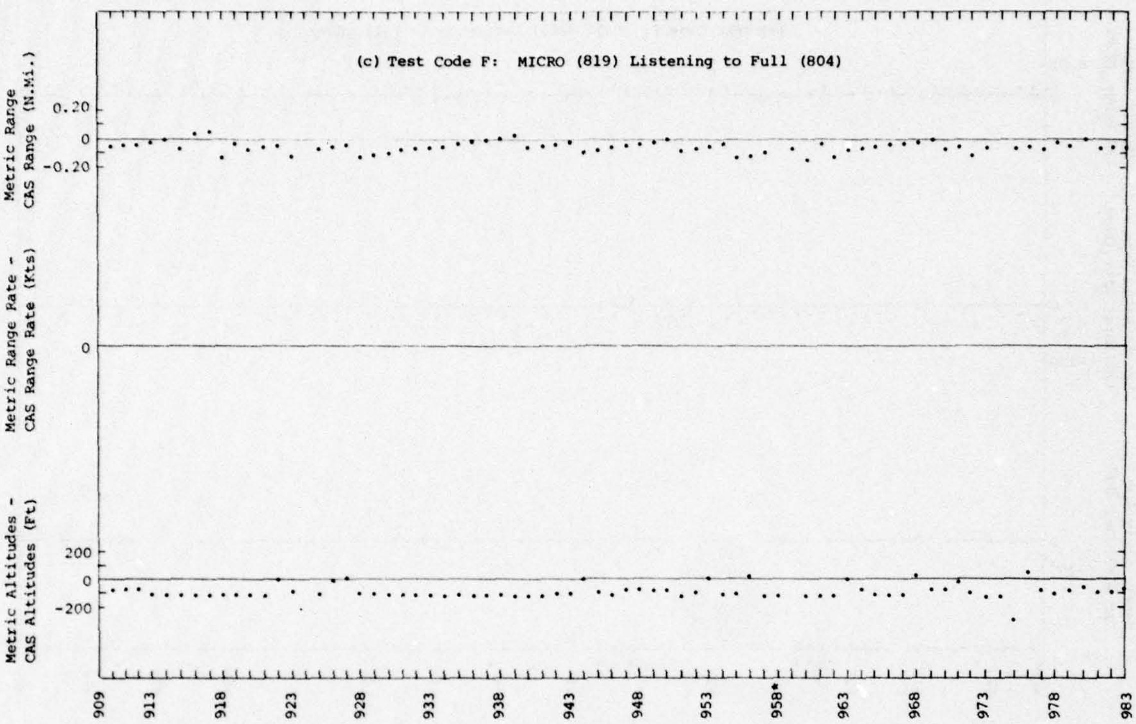


Figure 3-1. CAS MEASUREMENT ERRORS

(continued)



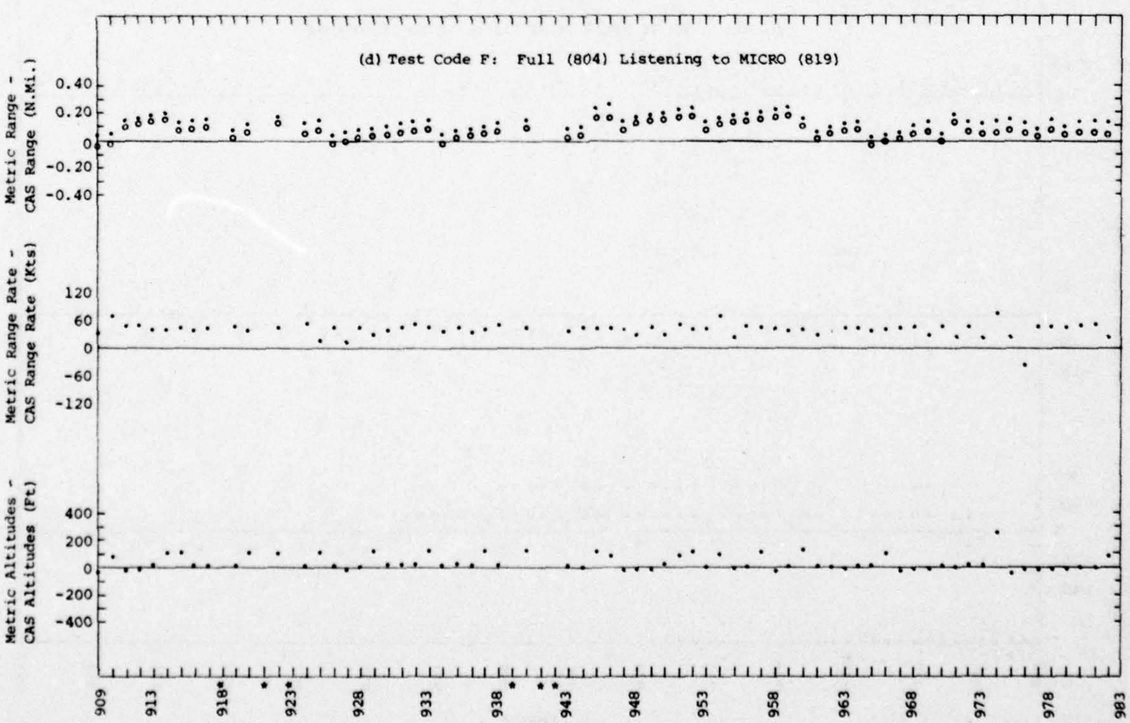


Figure 3-1. (continued)

(continued)

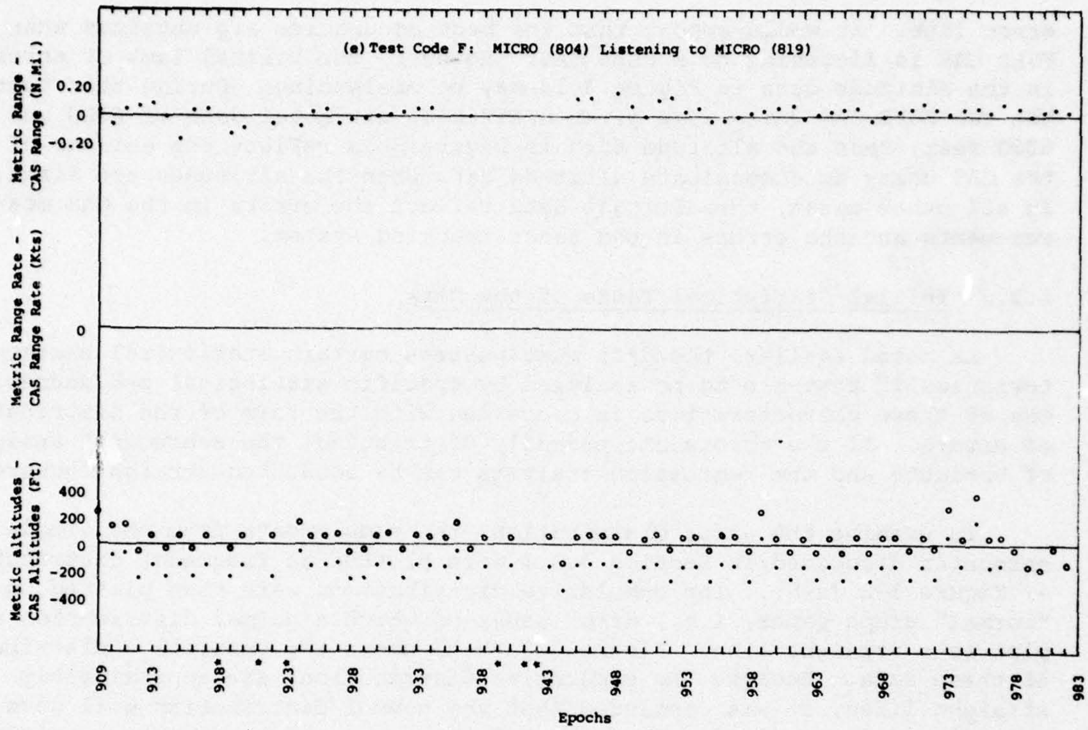


Figure 3-1. (continued)

- FULL CAS on C-131 #819 listening to MICRO CAS on C-131 #804
- MICRO CAS on C-131 #819 listening to FULL CAL on C-131 #804
- FULL CAS on C-131 #804 listening to MICRO CAS on C-131 #819
- MICRO CAS on C-131 #804 listening to MICRO CAS on C-131 #819

The point of closest approach occurred at epoch 973. The epochs with an asterisk indicate data drop-outs due to communications failures or (in the case of the MICRO CAS's) co-slot occupancy checking. The dots represent the raw data points, and the circles represent corrected data points. The corrections indicated in Figures 3-1b and 3-1e are due to a known failure of a flip-flop in the circuitry of the MICRO CAS on C-131 #804. The corrections indicated on Figure 3-1d are due to a known instrumentation problem in the McDonnell Douglas photo panel. Both of these problems are more fully described elsewhere in this report.

From these figures it is apparent that, in general, the range measurement errors are usually less than 0.1 n.mi., the range-rate errors are less than 100 knots, and the altitude errors are less than 150 feet. It is also apparent that there are biases in most of these measurements in that most of the data points will fall on one side or the other of the zero

error line. It would appear that the best accuracies are obtained when a FULL CAS is listening to a FULL CAS. However, the virtual lack of error in the altitude data in Figure 3-1a may be misleading. During this test, the two FULL CAS units were given artificial altimeter data of 6000 and 6200 feet; thus the altitude data in Figure 3-1a reflect the ability of the CAS units to communicate altitude data when the altitudes are fixed. In all other cases, the altitude data reflect the errors in the CAS measurements and the errors in the radar tracking system.

3.3.2 Initial Statistical Tests of the Data

As noted earlier, the data must possess certain statistical characteristics if they are to be analyzed by specific statistical procedures. One of these characteristics is concerned with the form of the distribution of errors. If the errors are normally distributed, the subsequent analyses of variance and the regression analysis can be conducted straightforwardly.

To examine the error distribution, the sample data from the single encounter discussed in Section 3.3.1 were plotted as frequency distribution -- Figure 3-2 (a-h). The cumulative distributions were then plotted on "normal" graph paper, i.e., graph paper on which a normal distribution will plot as a straight line. Figure 3-3 (a-h) shows the cumulative distribution of these data. Because the cumulative distributions are approximately straight lines, it was concluded that the normal distribution will give a satisfactory representation of the T/F CAS range and range-rate measurement errors. The quality of the altitude data was such that analysis of altitude errors was handled differently and less rigorously. The altitude errors indicated in Figure 3-1 (a-e) are affected by the radar measurement errors*, the altitude measurement errors, the altimeter digitalization, the CAS biasing when a threat is generated, and the CAS measurement errors. In order to eliminate some of these effects, several actions were taken. Data from those epochs in which a CAS threat was generated were not considered. Further, the difference between airborne altimeter readings was used as the standard against which the CAS-measured altitude separation was compared.

Table 3-1 shows the distribution of the altitude errors for the selected sample under these conditions. In general, the error could be evaluated only in 100-feet increments. However, the FULL CAS on C-131 #819 was instrumented with the ATA system that could measure altitude within 25 feet.

The tabulation of errors shown in Table 3-1 is not sufficient to establish the form of the error distribution. Certainly, it does not conclusively demonstrate that the distribution is normal. On the other hand, it does not indicate that the distribution is not normal, and, in general, an assumption of normality would not be unreasonable. Lacking more definitive information, we shall adopt this assumption in subsequent analysis of these data.

*In the case of altitude, the ground radar is not appreciably more accurate than the airborne altimeter.

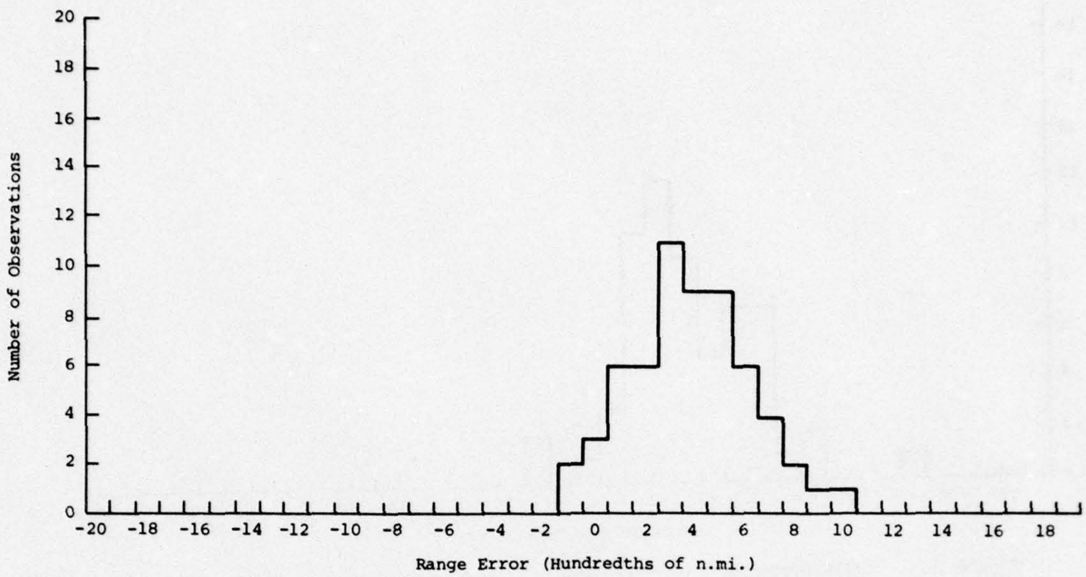


Figure 3-2a. DISTRIBUTION OF RANGE ERRORS - FULL (819) LISTENING TO FULL 804

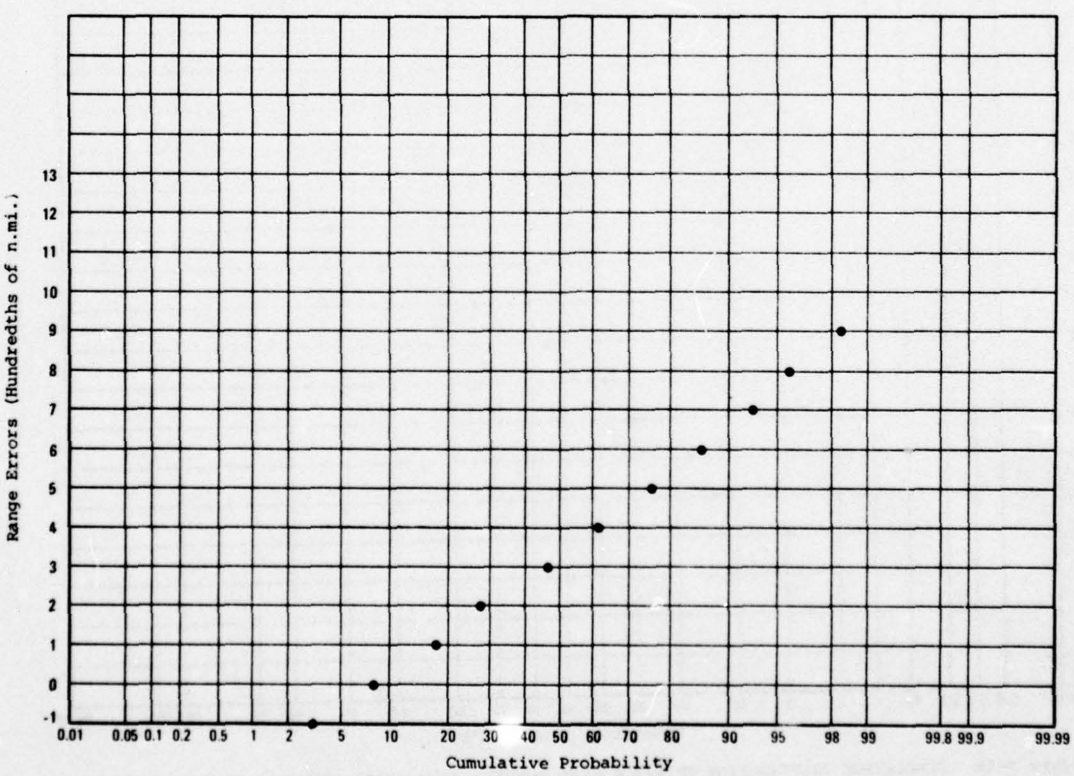


Figure 3-3a. CUMULATIVE DISTRIBUTION OF RANGE ERRORS - FULL (819) LISTENING TO FULL (804)

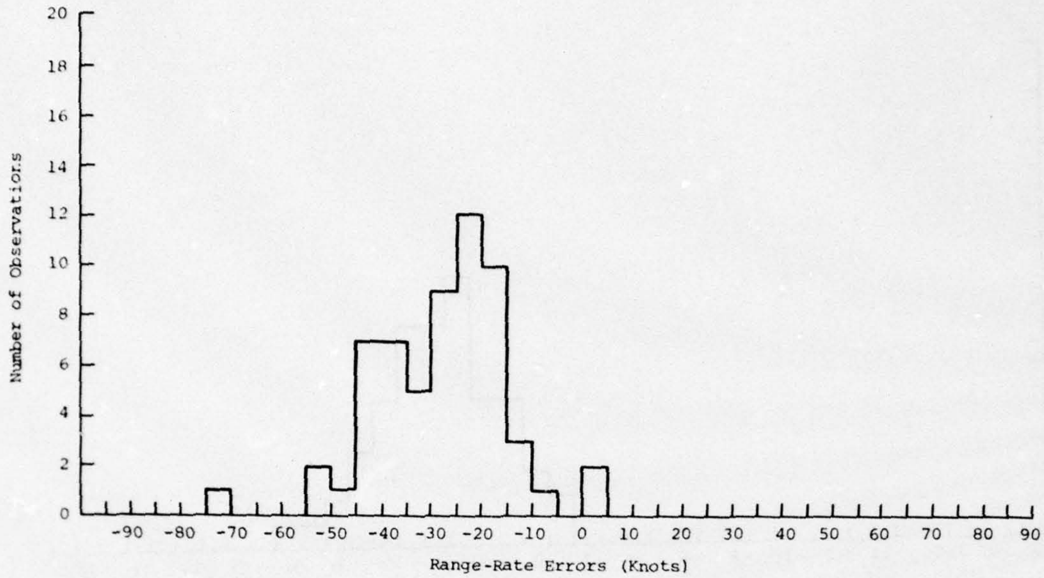


Figure 3-2b. DISTRIBUTION OF RANGE-RATE ERRORS - FULL (819) LISTENING TO FULL (804)

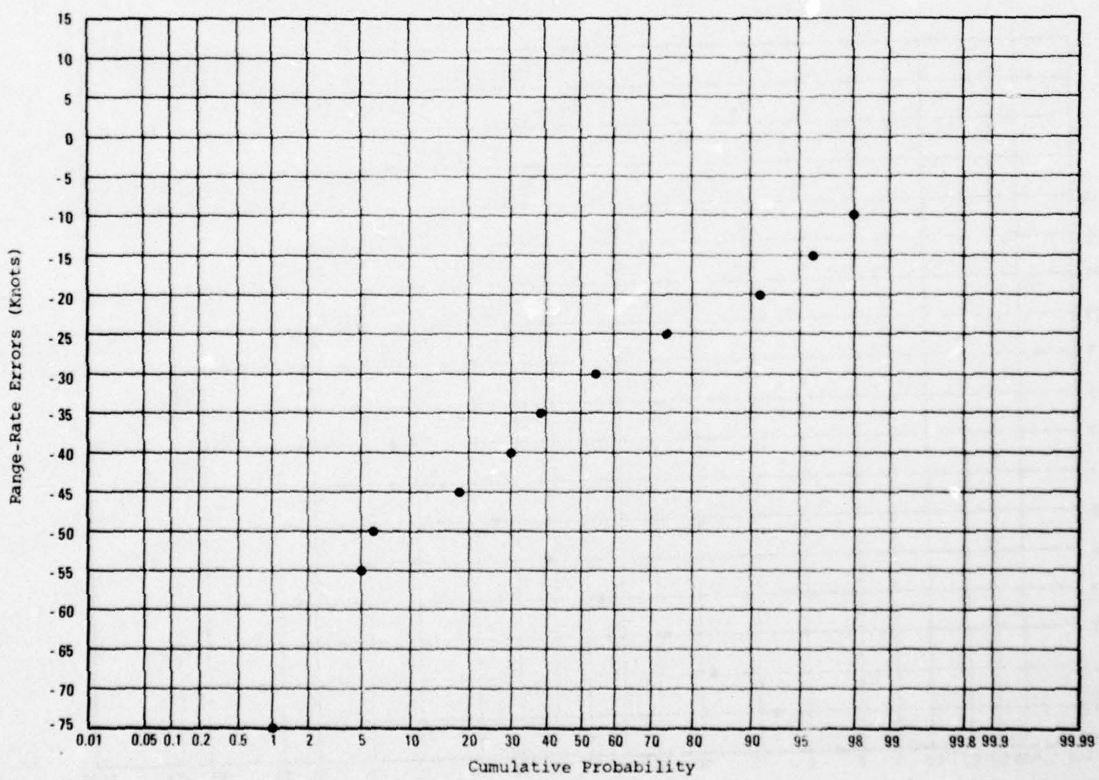


Figure 3-3b. CUMULATIVE DISTRIBUTION OF RANGE-RATE ERRORS - FULL (819) LISTENING TO FULL (804)

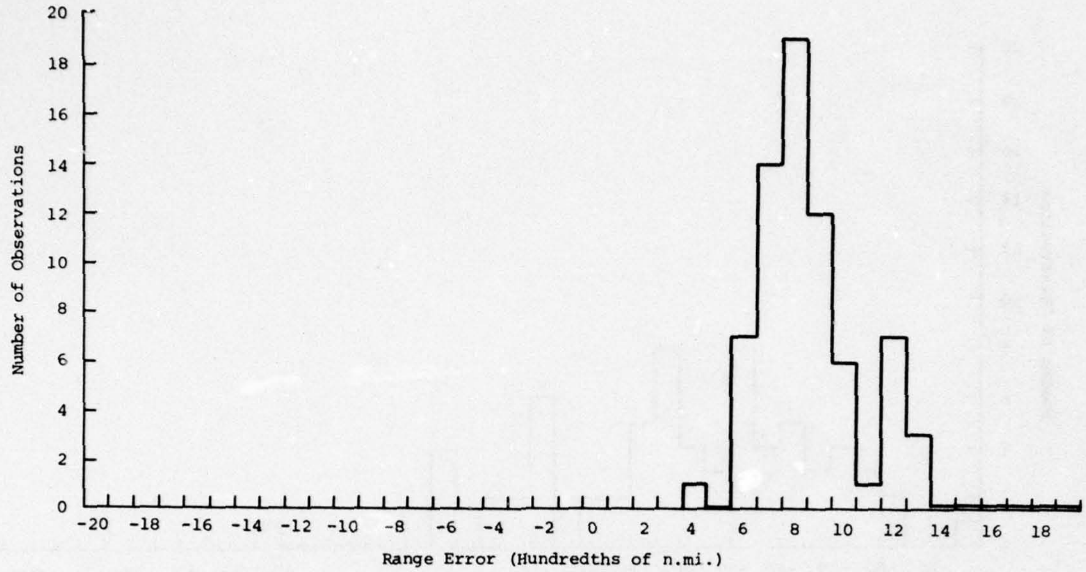


Figure 3-2c. DISTRIBUTION OF RANGE ERRORS - FULL (819) LISTENING TO MICRO (804)

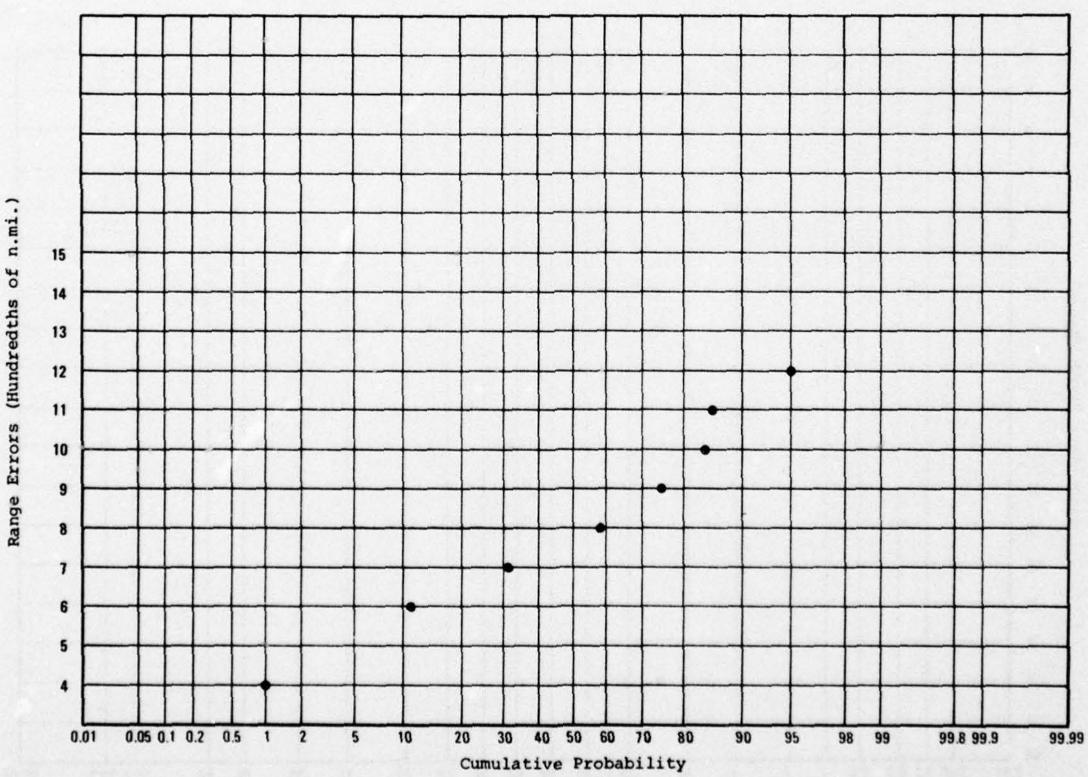


Figure 3-3c. CUMULATIVE DISTRIBUTION OF RANGE ERRORS - FULL (819) LISTENING TO MICRO (804)

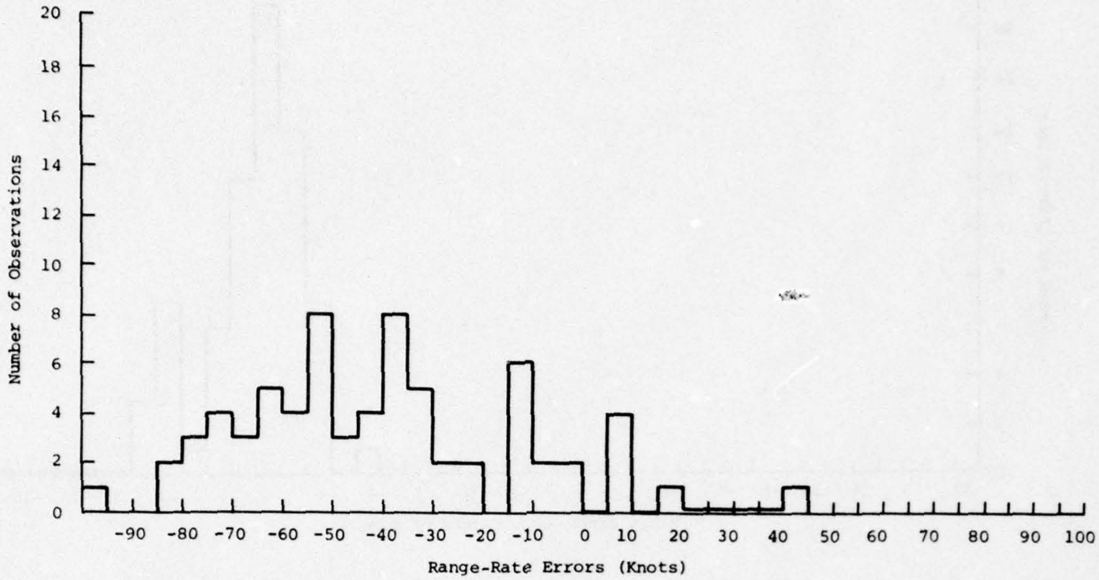


Figure 3-2d. DISTRIBUTION OF RANGE-RATE ERRORS - FULL (819) LISTENING TO MICRO (804)

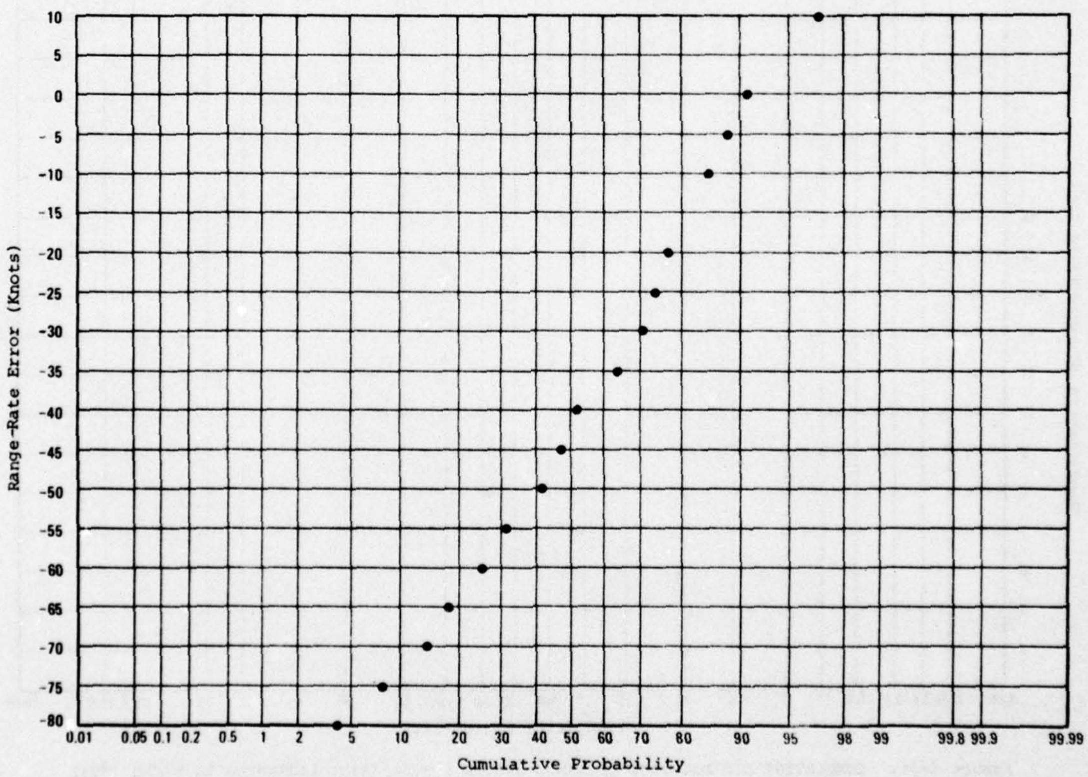


Figure 3-3d. CUMULATIVE DISTRIBUTION OF RANGE-RATE ERRORS - FULL (819) LISTENING TO MICRO (804)

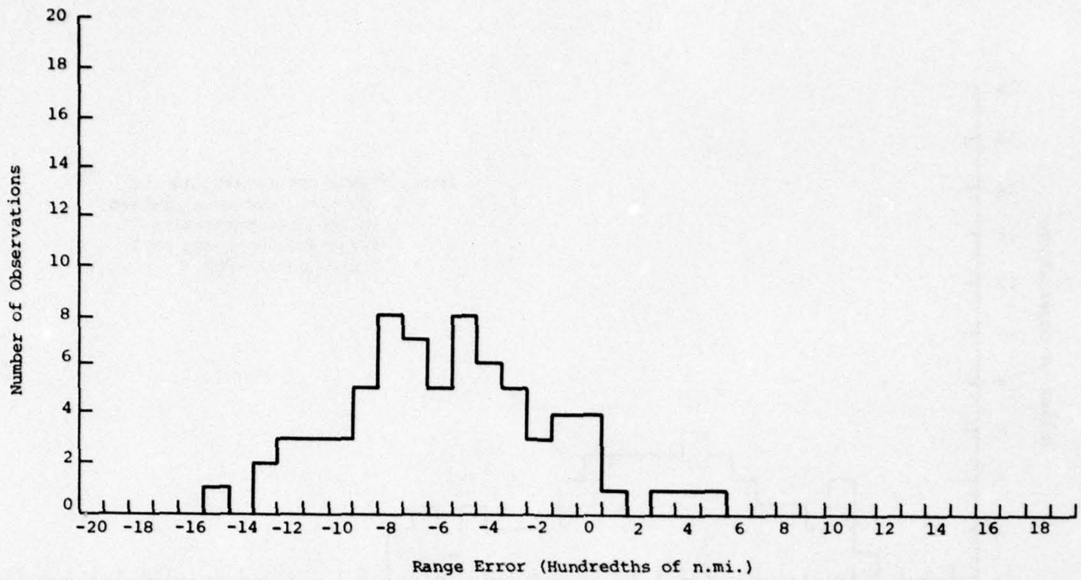


Figure 3-2e. DISTRIBUTION OF RANGE ERRORS - MICRO (819) LISTENING TO FULL (804)

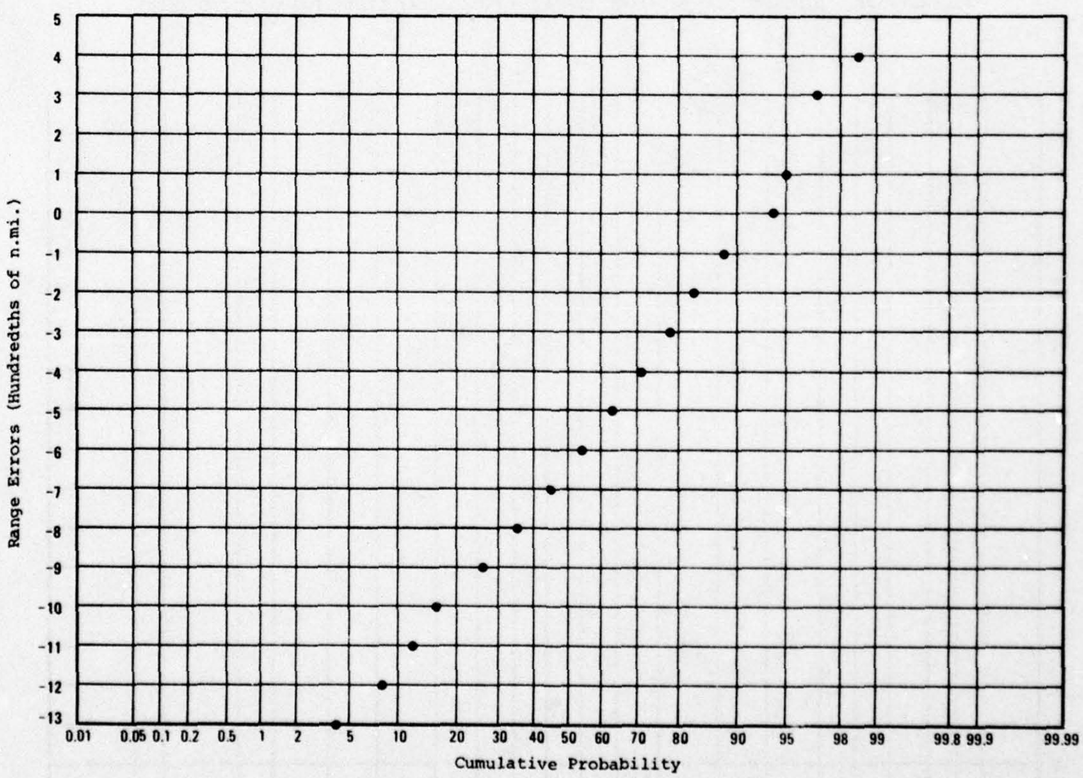


Figure 3-3e. CUMULATIVE DISTRIBUTION OF RANGE ERRORS - MICRO (819) LISTENING TO FULL (804)

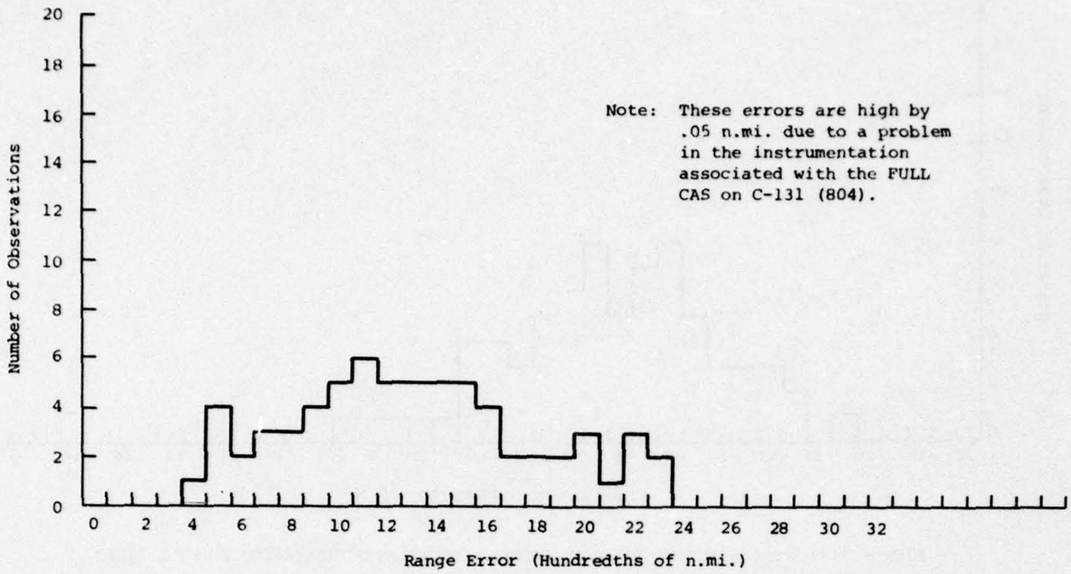


Figure 3-2f. DISTRIBUTION OF RANGE ERRORS - FULL (804) LISTENING TO MICRO (819)

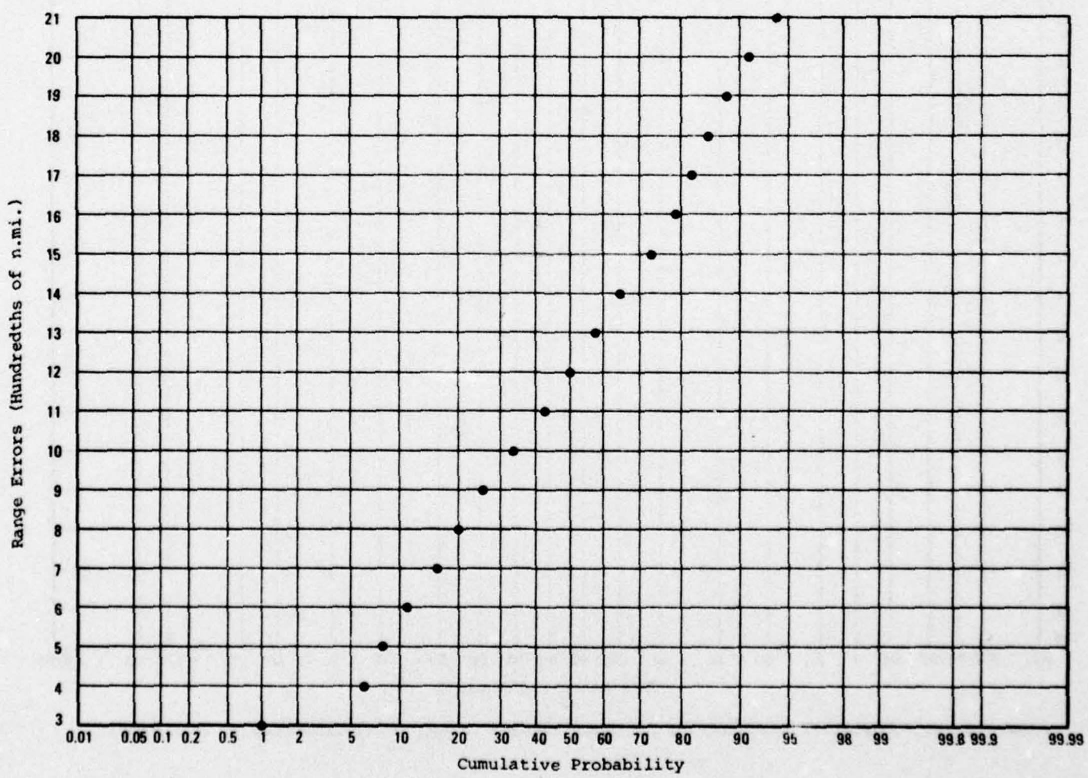


Figure 3-3f. CUMULATIVE DISTRIBUTION OF RANGE ERRORS - FULL (804) LISTENING TO MICRO (819)

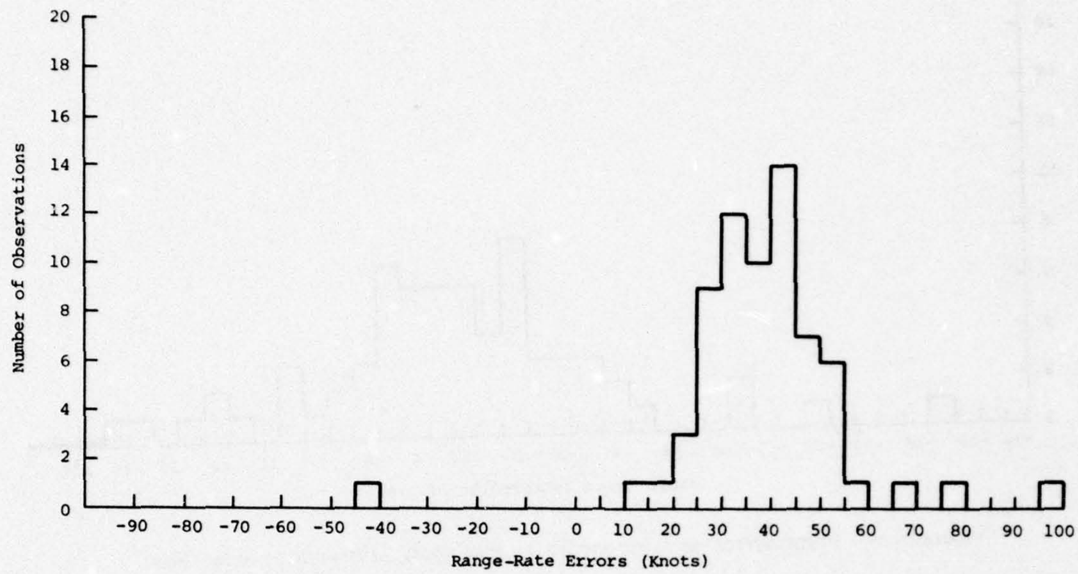


Figure 3-2g. DISTRIBUTION OF RANGE-RATE ERRORS - FULL (804) LISTENING TO MICRO (819)

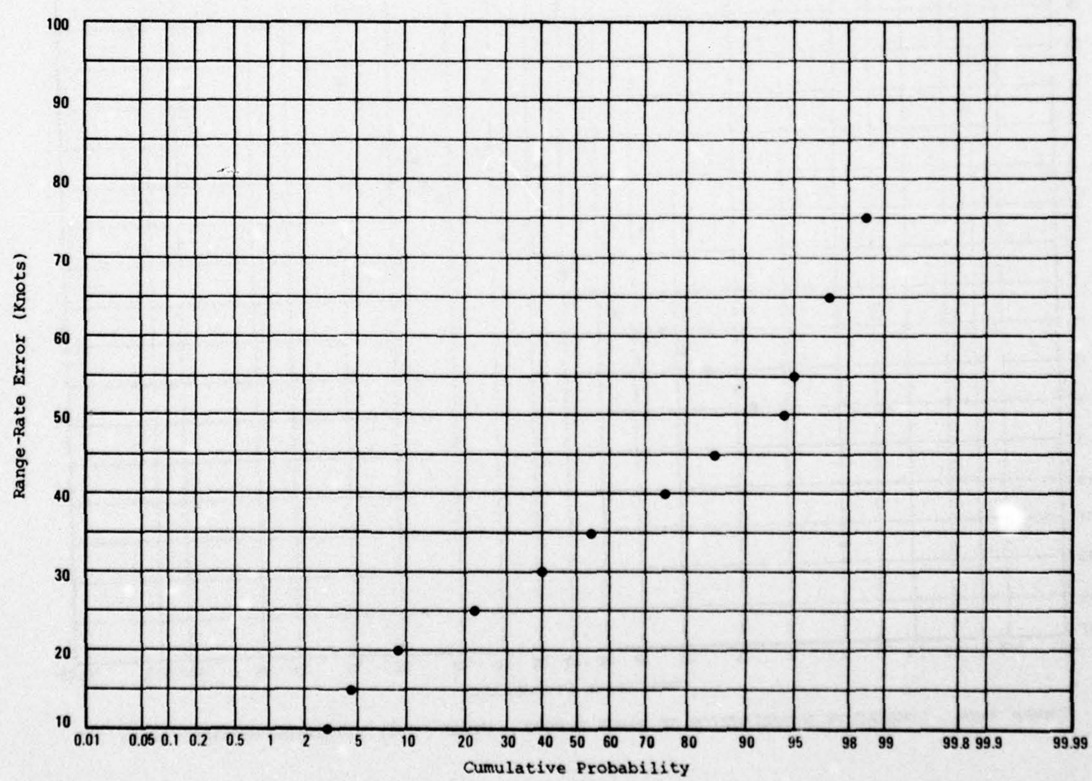


Figure 3-3g. CUMULATIVE DISTRIBUTION OF RANGE-RATE ERRORS - FULL (804) LISTENING TO MICRO (819)

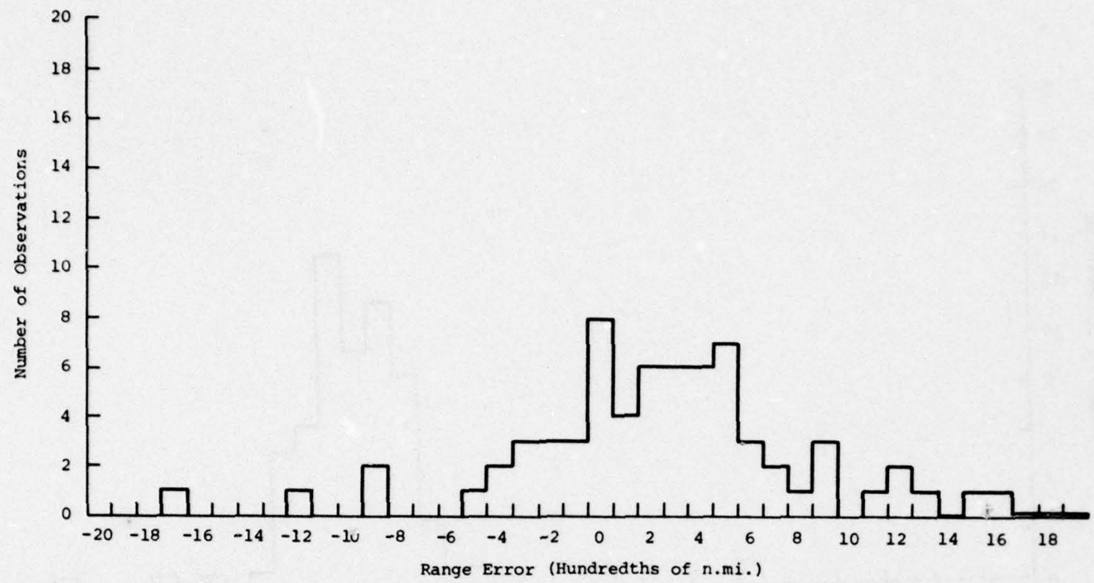


Figure 3-2h. DISTRIBUTION OF RANGE ERRORS - MICRO (804) LISTENING TO MICRO (819)

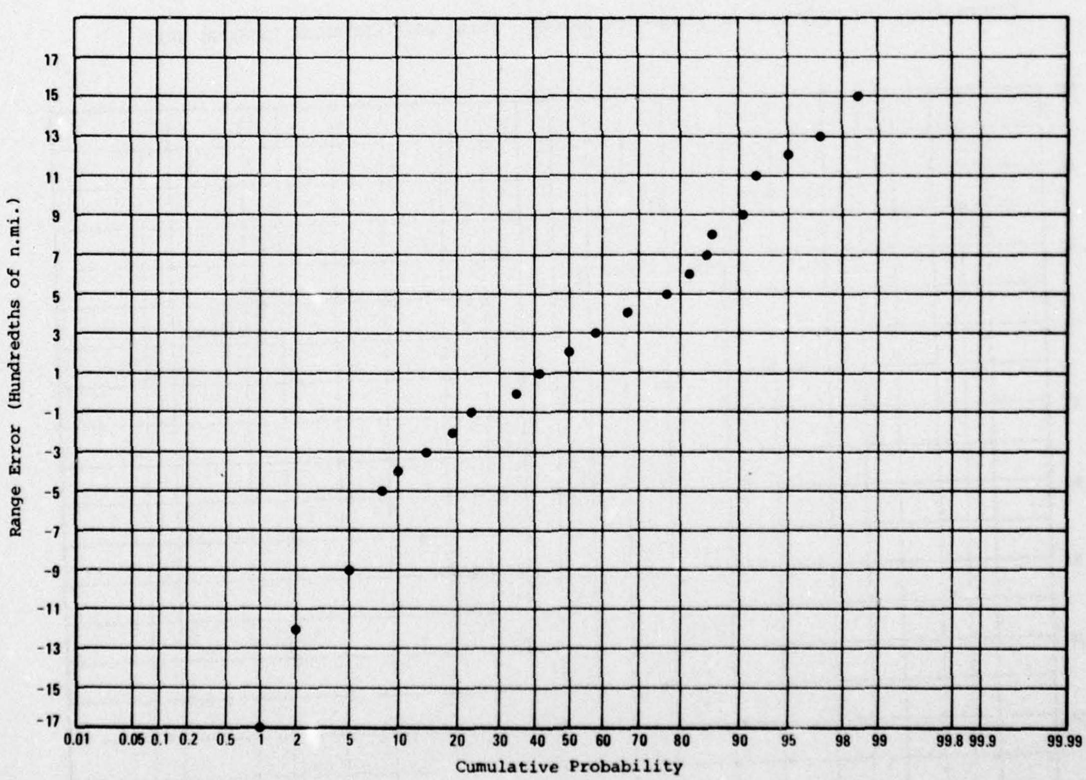


Figure 3-3h. CUMULATIVE DISTRIBUTION OF RANGE ERRORS - MICRO (804) LISTENING TO MICRO (819)

Table 3-1. SAMPLE DISTRIBUTION OF CAS ALTITUDE ERRORS (ALTIMETER READINGS MINUS CAS INDICATION)

System Combinations	Altitude Errors													
	-200	-150	-125	-100	-75	-50	-25	0	25	50	75	100	125	150
FULL CAS on C-131 #819 listening to FULL CAS on C-131 #804						8		23						
FULL CAS on C-131 #819 listening to MICRO CAS on C-131 #804			4		2		3		6		26			
MICRO CAS on C-131 #819 listening to FULL CAS on C-131 #804								34				4		
FULL CAS on C-131 #804 listening to MICRO CAS on C-131 #819				24				16						
MICRO CAS on C-131 #804 listening to MICRO CAS on C-131 #819	1			4				20				9		

3.3.3 Analysis of Variance

With these preliminary results in hand, we may now proceed with a determination of which test parameters influence the CAS errors.

It was possible that the range and range-rate error measurements of the CAS units would be a function of the test parameters (such as range, range rate, altitude separation, or altitude); therefore, it was necessary to analyze the data base for any possible relationships between the errors and the test parameters. The analysis of variance procedure was applied to determine which parameters, if any, affected the CAS errors. Appendix E provides a discussion of the analysis-of-variance technique on which the following results are based.

The analysis of variance required that the data base be sorted into a number of separate groups so that the variations between groups could be analyzed. The data were initially sorted into 800 groups defined by combinations of 4 range bins, 5 range-rate bins, 4 altitude-separation bins, 2 altitude bins, and 5 system categories. When sorted this way, many of the partitions contained no data, so it was necessary to combine the original groups to eliminate the empty partitions.* Hence, the analysis of variance was based on 2 range bins, 2 range-rate bins, and only those altitude-separation bins that applied to each of the system categories. A typical categorization of the CAS data is shown in Figure 3.4 for one of the system combinations.

The overall results of the analysis of variance are summarized in Table 3-2. The system combinations define the various combinations of MICRO and FULL CAS's. A distinction was made between the FULL CAS's on C-131 #819 and C-131 #804 because these two systems employ different instrumentation (the ATA digital instrumentation and the McDonnell Douglas photo panel, respectively). As will be shown later, there was a slight difference between these instrumentation systems that would not have been discovered had the FULL CAS data not been kept separated.

The restrictions on the analysis of variance dictate how the data had to be treated to avoid partitions that contained no observations. For example, the CAS data base contained data for three altitude separations and two altitudes for the full system on C-131 #819, but only four of the six altitude/altitude-separation cells contained data as indicated below:

Altitude Separation	Altitude No. 1	Altitude No. 2
No. 1	Data	No data
No. 2	Data	No data
No. 3	Data	Data

*The analysis-of-variance technique cannot treat a set of data in which many of the partitions are empty.

Data Categories				Average Errors		Number of Data Points
Range (N.mi.)	Range Rate (Knots)	Altitude Separation (Feet)	Altitude	Range (N.mi.)	Range Rate (Knots)	
0-4	0-150	More than 800 below	Low*	.08555	-33.71	722
0-4	0-150	More than 800 below	High**	.08962	-36.36	707
0-4	150 or more	More than 800 below	Low*	.07125	-35.22	32
0-4	150 or more	More than 800 below	High**	.07444	-26.76	54
4 or more	0-150	More than 800 below	Low*	.08151	-22.71	199
4 or more	0-150	More than 800 below	High**	.08360	-32.36	100
4 or more	150 or more	More than 800 below	Low*	.05141	-23.83	319
4 or more	150 or more	More than 800 below	High**	.04986	-24.43	282

*Low altitude - approximately 2000 feet.
**High altitude - approximately 10,000 feet.

Figure 3-4. ANALYSIS-OF-VARIANCE DATA MATRIX FOR THE FULL CAS ON C-131 (#819) LISTENING TO THE MICRO CAS ON C-131 (#804)

Therefore, the analysis of variance of the data for the FULL CAS on C-131 #819 was broken into two parts; one part considered only data for altitude separation No. 3, and the second part considered only data for altitude No. 1. The "Restrictions on the Analysis" indicate the two parts into which the data from the FULL CAS on C-131 #819 were broken.

The analyses of range and range-rate errors identified those variables that significantly influenced the errors. For example, the first entry in Table 3-2 indicates that, for the FULL CAS in #819 listening to the FULL CAS in #804, the "range" had a significant effect on the range error. Statistical tests showed that the factors indicated in Table 3-2 were significant at the 5 percent level; i.e., only 5 percent of the time would significance be indicated when the factor did not have a significant effect. This level is generally considered to indicate that the factor is, in fact, a true influence on the error.

Table 3-2. ANALYSIS OF VARIANCE RESULTS

System Combination†	Restrictions on the Analysis	Range Error Analysis: Significant Variables	Range Error Analysis: Variation in Average Range Error	Range-Rate Error Analysis: Significant Variables	Range-Rate Error Analysis: Variation in Average Range-Rate Error
Full CAS on 819 listening to Full CAS on 804	Single altitude separation	Range Range rate	.032 n.mi.* .024 n.mi.	Range	10.1 kts.
Same as above	Single altitude	Altitude separation Range Range rate	.020 n.mi. .022 n.mi. .013 n.mi.	Range rate	5.3 kts
Full CAS on 819 listening to MICRO CAS on 804	Single altitude separation	Range Range rate Range/range rate	.025 n.mi. .033 n.mi.* .037 n.mi.*	Range rate Altitude/range	10.0 kts. 11.1 kts.
Same as above	Single altitude	Altitude separation Range Range rate	.018 n.mi. .025 n.mi. .036 n.mi.*	None	
Full CAS on 804 listening to MICRO CAS On 819	None	Altitude separation Range	.013 n.mi. .027 n.mi.	Altitude separation Range Altitude separation/ range	6.3 kts. 3.4 kts. 11.0 kts.
MICRO CAS listening to Full CAS	None	Altitude Range rate Range/range rate	.000 n.mi. .013 n.mi. .023 n.mi.	NA	
MICRO CAS listening to MICRO CAS	None	None		NA	

†The system combinations differentiate between the FULL CAS on C-131 #819 and C-131 #804 because these systems are instrumented differently.

*These variations are greater than the errors that the ANTC 117 threat logic was designed to tolerate.

In addition to statistical significance, the factors were considered from an engineering point of view. Criteria were developed to determine what levels of error variations were meaningful in terms of system performance. The approach to establishing these criteria is outlined in the following paragraphs.

The ANTC 117 threat logic served as a basis for determining the permissible variations in range and range-rate errors. The Tau 1 threat boundary is defined by the equations

$$R = 25\dot{R} + 0.25 \qquad R > 0.5$$

$$R = 0.5 \qquad \text{Otherwise}$$

where

R = range (n.mi.)

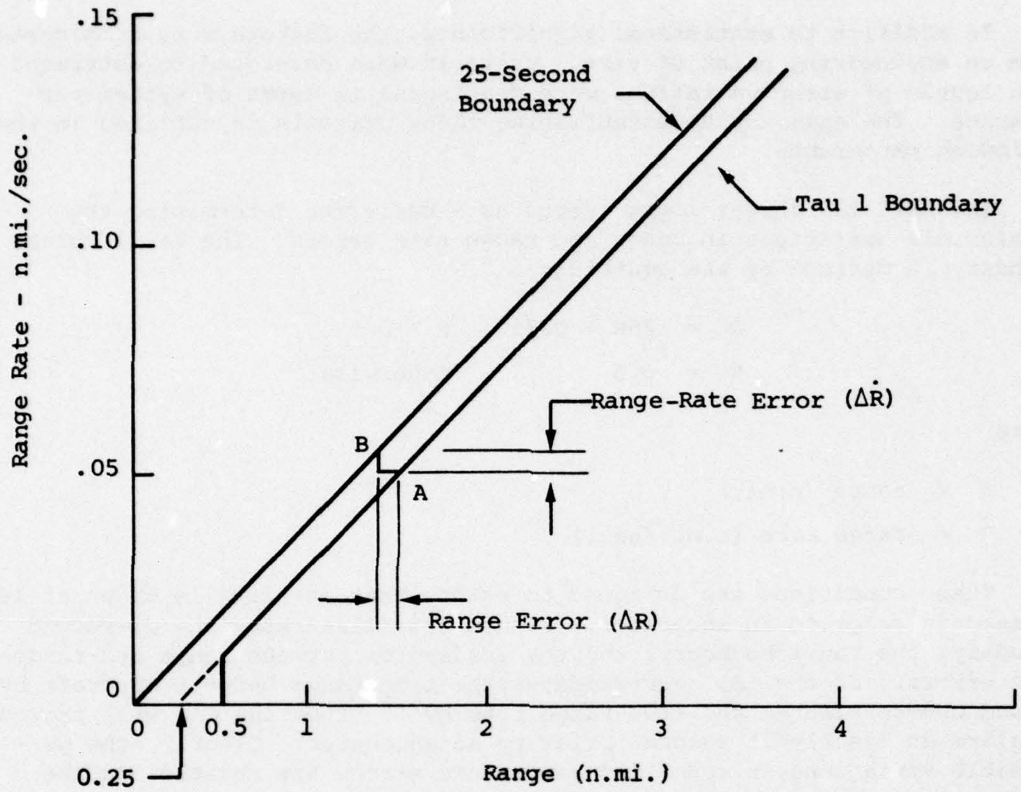
$\dot{R}$ = range rate (n.mi./sec.)

These conditions are designed to ensure that an alarm is given at least 25 seconds prior to an encounter. Figure 3-5 illustrates the 25-second boundary, the Tau 1 boundary, and the trade-offs between range and range-rate errors. If the CAS overestimates the true range between aircraft by ΔR and underestimates the true range rate by $\Delta\dot{R}$, then the CAS will provide an alarm at exactly 25 seconds prior to an encounter. Clearly, the permissible variations in range and range-rate errors are related and the tolerance in one error term must be assumed so that the other can be calculated. Because the T/F CAS concept is implemented by using digital logic with a 5-MHz clock rate, it was considered reasonable that the T/F CAS units should be able to measure range with a resolution corresponding to no more than a clock count. Therefore, the permissible average range error was chosen to be 0.032 n.mi. The corresponding permissible average range-rate error becomes 31.4 knots.

From Table 3-2, it can be seen that none of the variations in the average range-rate error exceeds the 31.4-knot limit and only four of the variations in the average range error exceed the 0.032-n.mi. limit.

On the basis of the results of the statistical and engineering evaluations, then, the following statements can be made:

- Range error for FULL CAS systems is significantly affected by range and range rate. Therefore, the data should be analyzed to evaluate these effects.
- The range-rate errors are independent of any test parameters, and all of the range-rate data can be combined.
- The MICRO CAS range errors are independent of any test parameters, and all of the MICRO CAS range data can be combined.



A	-	Range and range-rate estimates made by the CAS to first generate a threat
B	-	Actual range and range rate that would correspond to 25 seconds prior to an encounter (assuming constant closing rate between aircraft)
ΔR, $\Delta\dot{R}$	-	Range and range-rate errors that could be made by the CAS and still provide a command 25 seconds prior to the encounter

Figure 3-5. EFFECTS OF RANGE AND RANGE-RATE ERRORS

It was somewhat surprising that the ability of a full system to measure range would be a function of the range and range rate between aircraft, while the ability of a MICRO CAS would be unaffected. However, discussions with McDonnell Douglas indicated that the FULL CAS units had a narrower bandpass filter on the IF than did the MICRO CAS. This caused the FULL CAS range measurements to be sensitive to the received signal strength because the range is determined by the time the received range pulse crosses a preset threshold. Figure 3-6 illustrates the possible variations in received range pulse time. Therefore, the difference between the true range and the CAS-measured range should decrease with increasing range. The absolute error becomes less with increasing range because the FULL CAS has been compensated to underestimate the range when the received signal is strong. No technical explanation is available for the effect of range rate on the FULL CAS range-measurement errors, but this effect was considered in developing the error models nevertheless.

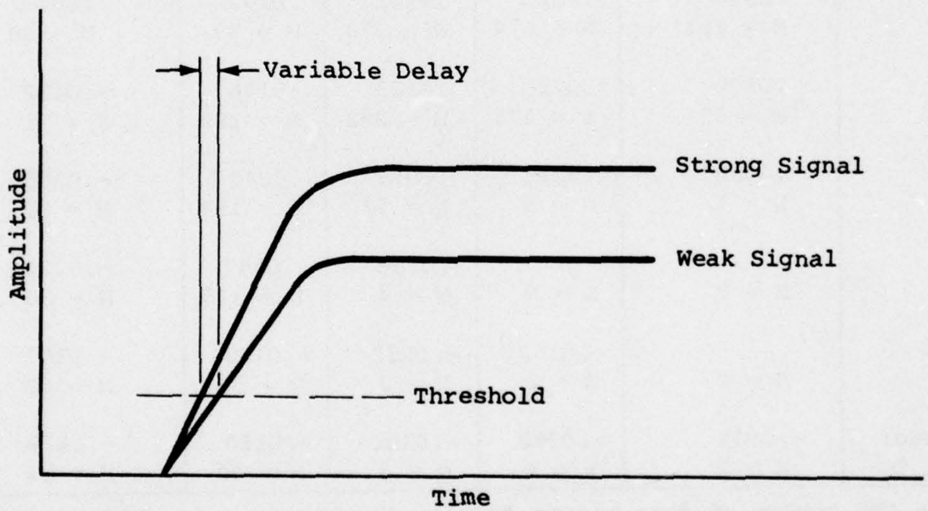


Figure 3-6. VARIABLE TIME DELAY DUE TO RECEIVED SIGNAL AMPLITUDE

3.3.4 Development of T/F CAS Error Models

The analysis of variance indicated those factors that should be considered in developing the error models. On the basis of those results, the range data for the FULL CAS systems were divided into range and range-rate bins so that the effect of range and range rate on the FULL CAS range measurements could be determined. The MICRO CAS range data, the range-rate data, and the altitude data were combined into one large data set from which the mean error and standard deviation were derived.

To generate the range-error models for the FULL CAS systems, the average range errors for 30 range/range-rate combinations (based on 6 range levels and 5 range-rate levels) were determined. The large number of combinations was used to provide a better representation of the effect of range and range rate on the CAS range errors. Table 3-3 indicates the average range errors for one of the system combinations.

Table 3-3. DISTRIBUTION OF MEAN RANGE ERRORS FOR THE FULL CAS ON C-131 #819 LISTENING TO THE FULL CAS ON C-131 #804

True Range (N.mi.)	True Range Rate (Knots)				
	Less than 0*	0-50	50-150	150-350	Greater than 350
0-2	.0348 N = 263	.0225 N = 674	.0201 N = 273	.0193 N = 99	.0049 N = 38
2-4	.0198 N = 80	.0210 N = 475	.0103 N = 262	.0146 N = 193	-.0172 N = 71
4-6	.0038 N = 1	.0018 N = 5	.0059 N = 52	.0042 N = 154	-.0200 N = 69
6-8	N = 0	N = 0	.0288 N = 4	-.0047 N = 115	-.0220 N = 66
8-10	N = 0	-.0162 N = 2	-.0212 N = 8	-.0189 N = 55	-.0307 N = 40
Greater than 10	-.0012 N = 2	-.0262 N = 1	-.0362 N = 3	-.0350 N = 40	-.0479 N = 53

N is the number of data points falling in the given range/range-rate bin.

*This column of data not used in the regression analysis.

The data in Table 3-3 were used to generate a linear regression model for the average range error of the form:

$$\text{Average range error} = A_o + A_1 R + A_2 \dot{R}$$

where

R = true range

$\dot{R}$ = true range rate

$$
\left.\begin{array}{l} A_o = \\ A_1 = \\ A_2 = \end{array}\right\} \text{Constants to be determined by regression analysis}
$$

In the analysis, the values in the table were weighted by the number of observations (N).

The regression analysis provided the following result:

$$\text{Average range error} = .0334 - .00390R - .0000686\dot{R}$$

The coefficient of determination (R^2) for the equation is 0.91. This indicates that 91 percent of the variation in the mean range errors is explained by this equation. The standard deviation of individual range errors about the regression model was found to be 0.0279 n.mi. This standard deviation was derived from the standard deviation of the 2752 individual observations, the standard deviation of the means in Table 3-3, and the stated R^2.*

Table 3-4 shows the regression model for the average range error, the standard deviation about the average-range-error equation, and the mean and standard deviation of the 2752 data points prior to performing the regression analysis. The same steps were performed to derive the average-range-error models for the other full system combinations in Table 3-4.

The remaining entries in Table 3-4 represent the mean and standard deviation of the range, range-rate, and altitude errors for all of the two-aircraft-encounter data points in the CAS data base. It has been shown that the CAS errors are normally distributed; thus the resulting error models are given by

$$p\,(\varepsilon) = \frac{1}{\sqrt{2\pi\sigma^2}}\, e^{-(\varepsilon - m)^2/2\sigma^2}$$

where

p (ε) is the probability density of the error (either range, range-rate, or altitude error)

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*By algebraically expanding $E[Y_i - \bar{Y}_i]^2$, where Y_i is the ith observation and $\bar{Y}_i$ is the corresponding regression estimate, it can be shown that the regression line for individual observations can be estimated by $\sigma^2_Y - R^2_{(\bar{Y}_i - \bar{\bar{Y}})}\,\sigma^2_{(\bar{Y}_i - \bar{\bar{Y}})}$ where σ^2_Y is the population variance, $R^2_{(\bar{Y}_i - \bar{\bar{Y}})}$ is the coefficient of determination based on a regression using means, and $\sigma^2_{(\bar{Y}_i - \bar{\bar{Y}})}$ is the variance of the means about the overall mean.

Table 3-4. T/F CAS ERROR-MODEL PARAMETERS

System Combination	Range Error Model		Range-Rate Error Model		Altitude Error Model	
	Mean Error	Standard Deviation	Mean Error	Standard Deviation	Mean Error	Standard Deviation
FULL CAS on 819 listening to FULL CAS on 804	.0334 - 00390R -.0000686$\dot{R}$ {.0144} (R^2 = .91)	.0279 {.0311}	-17.2	40.8	22.8	46.0
FULL CAS on 819 listening to MICRO CAS on 804	.0838 - .00517R -.0000386$\dot{R}$ {.0576} (R^2 = .85)	.0332 {.0382}	-26.9	39.2	55.5	67.0
FULL CAS on 804 listening to MICRO CAS on 819	.115 - .00373R -.0000462$\dot{R}$ {.0980} (R^2 = .57)	.0553 {.0568}	40.3	21.5	-63.1	61.2
MICRO CAS listening to FULL CAS	-.0512	.0557			17.9	38.5
MICRO CAS listening to MICRO CAS	.001	.0573			20.4	108.6

R - Range in nautical miles.

$\dot{R}$ - Range rate in knots.

{ } - Mean error and standard deviation prior to fitting a regression model to the data.

R^2 - Coefficient of determination.

σ = the standard deviation given in Table 3-4 for the range, range rate, or altitude for the given system combination

m = the mean error given in Table 3-4 for the range, range rate, or altitude for the given system combination

In the range-error model for a full system, the parameter "m", is functionally related to the range, R, and the range rate, $\dot{R}$, as described above.

A number of comments can be made regarding some apparent discrepancies in the results in Table 3-4. There is a difference in the average range error between the case of the FULL CAS on C-131 #819 and the FULL CAS on C-131 #804 when each is listening to a MICRO CAS. There appeared to be no reason to expect two identical CAS units to measure range differently; therefore, the McDonnell Douglas engineers were questioned about this problem. After a brief analysis, McDonnell Douglas concluded that the photo panel instrumentation on the FULL CAS in C-131 #804 was not calibrated properly and that the improper calibration would result in a 0.05-n.mi. measurement error.

The average range errors between two FULL CAS units or between two MICRO CAS units were very small, but the average range errors for a FULL CAS listening to a MICRO CAS or for a MICRO CAS listening to a FULL CAS were about 0.05 n.mi. and of opposite sign. This discrepancy was anticipated by McDonnell Douglas because the MICRO CAS internal timing delays to compensate for transmitter and receiver rise times and antenna delays were known to be off by 0.3 microsecond prior to the start of the test program. A 0.3-microsecond timing delay error would contribute exactly a 0.0486-n.mi. range error between properly calibrated FULL CAS equipments and improperly calibrated MICRO CAS equipments.

The spread of average range-rate errors among the various system combinations is not surprising, because a slight offset in either one of the CAS oscillators will cause a range-rate measurement error. An offset of 1 part in 10^8 is extremely small but will still yield a 5-knot range-rate measurement error. In addition, any spurious amplitude modulation in the range pulse will contribute to a range-rate measurement error and could easily be much larger than 5 knots. Therefore, discrepancies in the average range-rate errors are expected.

The average altitude errors are generally small except for the case of a FULL CAS listening to a MICRO CAS. The large errors for this case are unexplained but could be due to a combination of timing-delay problems in the MICRO CAS and instrumentation problems with the McDonnell Douglas photo panel. The standard deviations for the altitude measurement errors are generally about equal to a clock count or about 0.2 microsecond (recall that 0.2 microsecond corresponds to 50 feet). The large standard deviation for the MICRO CAS equipments is completely unexplained. However, it is believed that an intermittent failure in the MICRO CAS on C-131 #804 may be partly responsible for some of the observed variation. Every effort was made to eliminate problems from the CAS altitude data, including neglecting epochs during which the CAS altitude is biased due to a threat's being

generated and subtracting the effect of a failed flip-flop in the MICRO CAS on C-131 #804. This latter problem caused a great deal of concern until a pattern was recognized in the data associated with that system.* In spite of these efforts, the standard deviation of the MICRO CAS altitude errors still seems too large, but the analysis of the altitude-measurement capability of the MICRO CAS will be based on the values shown in Table 3-4.

The foregoing analysis was performed on the data from the two-aircraft-encounter missions. It was believed that the supersonic-mission data had to be treated separately, and this mission is discussed in a later section. The BUM and three-aircraft-encounter mission data were not included in the above analyses because the T/F CAS equipment does not measure range when operating in the back-up mode and because the three-aircraft-encounter data involved extra systems and would have complicated the purely mechanical problems of data analysis. The traffic-pattern tests and the radar-altimeter tests were not originally included in the analysis, because it was suspected that the CAS equipments might have operated differently during these tests. However, a subsequent error analysis in which the traffic-pattern and radar-altimeter test data were included in the computations revealed no significant difference between the new results and the results already reported. For example, the mean range error for the FULL CAS on C-131 #819 listening to the FULL CAS on C-131 #804 when the traffic pattern and radar-altimeter data were included was

$$\textit{Mean range error} = .0315 - .00386P - .0000654\dot{R}$$

This is very close to the equation reported in Table 3-4. Therefore, it was assumed that the two-aircraft-encounter data gave an adequate representation of the T/F CAS systems even when at traffic-pattern altitudes or when an AN/APN-159A radar altimeter was operating. However, the AN/APN-159A radar altimeter did cause more frequent data dropouts, which will be discussed shortly.

3.3.5 Prediction of CAS Horizontal Alarm Boundaries

The error models described in Section 3.3.4 fulfill the basic requirement to provide a characterization of the CAS measurement accuracies. As noted earlier, however, an extension from these results into alarm performance for specific mission situations will provide additional insight into the system's capability. To accomplish this, a method was developed for expressing the probability of alarm -- and, conversely, the probability of no alarm -- as a function of the error models for specific mission situations. Appendix F provides a detailed basis for analyzing the distribution

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*This led ARINC Research to question McDonnell Douglas about the circuitry in that particular unit. As a result, McDonnel Douglas identified a failed flip-flop that caused 0, 200, and 400 ft. altitude errors in that system.

of ranges and warning times at which an alarm is given based on the error models developed in Section 3.3.4. It is emphasized that this approach is based on the assumption that the aircraft are converging at a constant closing rate. This assumption is reasonable in almost all encounters and is strengthened by the fact that the CAS will generate a no-turn command to ensure a constant closing rate after the Tau 1 boundary is penetrated. The assumption, of course, does not imply that the range rate as measured by CAS will remain constant from epoch to epoch even though the true rate is constant.

Employing the results of Appendix F and Table 3-4 to examine a few special cases reveals that the CAS range errors have little practical impact on the time or range at which an alarm is given. Figure 3-7 shows the probabilities of a CAS alarm at various ranges for a 30-knot constant closing rate for a FULL CAS system listening to a FULL CAS system. Four probability curves are indicated. Two curves are based on the error models of Section 3.3.4, and two are based on a hypothetical CAS equipment that never makes a range-measurement error but measures range rate with the errors given in Section 3.3.4. The curves labeled "probability of a CAS alarm at range R_T" indicate the probability that an alarm will be generated given that

- The aircraft are closing at 30 knots ($\dot{R}_T$).
- The aircraft are at the stated range (R_T).
- The assumed error models apply.
- One aircraft transmits a single CAS range-altitude pulse pair at the assumed range and range rate that is received and processed by the other aircraft.

The curves labeled "probability of no alarms at or before range R_T" represent the probability that an alarm will not be given at range R_T times the product of the probabilities that no alarm will be given during any of the epochs prior to range R_T. That is,

$$\text{Probability of no alarms prior to range } R_T = \prod_{K=o}^{\infty} [(1 - P(R_T + k\dot{R}_T t)]$$

where

$P(R_T + k\dot{R}_T t)$ = probability of a CAS alarm at range $R_T + k\dot{R}_T t$

$\dot{R}_T$ = range rate (assumed constant)

t = 3 seconds (one epoch)

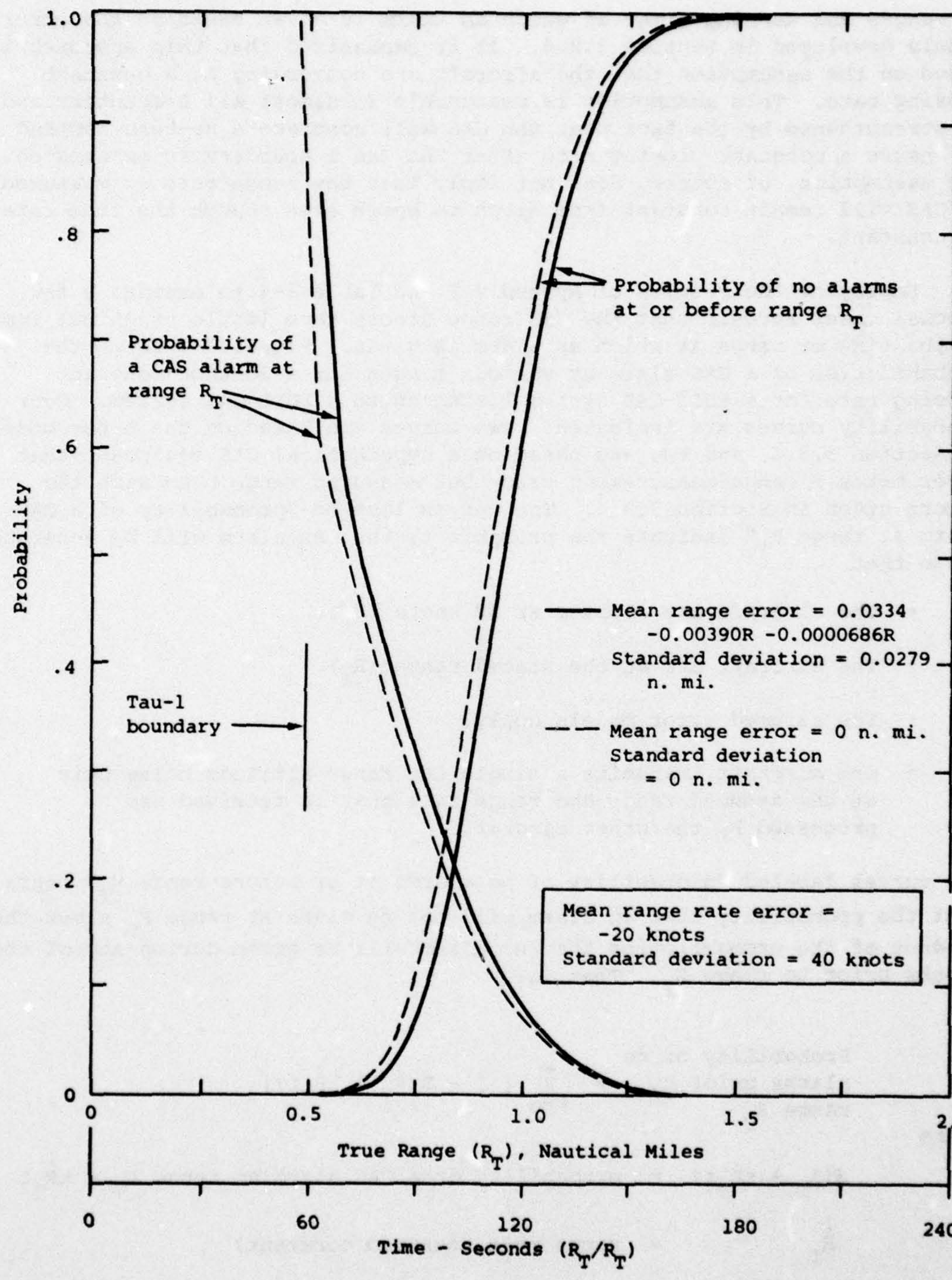

Figure 3-7. **PROBABILITY OF FULL CAS ALARMS FOR A TRUE RANGE RATE OF 30 KNOTS**

It can be seen from Figure 3-7 that there is little difference in the range at which alarms are likely to be generated whether the range-error model is used or not. Figures 3-8 and 3-9 illustrate other closing rates and average range-rate errors. It can be seen that the above conclusion is not affected. The average range-rate error of +20 knots was included even though the T/F CAS data do not support this assumed value, because variations in T/F CAS equipments are to be expected, and the fact that a full system did not measure a second full system's range rate with a positive average bias during the current test program does not mean that it could not occur between actual production systems.

For the MICRO CAS, the alarm boundary is defined by the range only; therefore, the corresponding probabilities of an alarm and of no alarm prior to R are given in Figure 3-10 for a MICRO CAS listening to a full system. While the MICRO CAS does not measure range rate, the closing rate will have a slight effect on the "probability of no alarm prior to R_T" curve because the range between successive epochs varies with range rate. However, it can be seen that this effect is very small.

The above analysis of the Tau or range boundaries could be extended to cover the CAS warning boundaries, with similar results being obtained. It should be pointed out that these models do not consider the possibility of communications failures (either real or those due to co-clot checking) or the fact that two aircraft are involved in the encounter. The communications dropouts would lower the probability of receiving an alarm by the probability of a dropout at that point in time. When two aircraft are involved in an encounter, both are processing range and range-rate data; the probability of either or both generating an alarm is therefore important. The results of Figures 3-7 through 3-10 could be extended easily to cover this situation.

3.3.6 Prediction of CAS Altitude Boundaries

The probability that a CAS will or will not consider a second CAS to be within its co-altitude band (i.e., within ±600 feet) can be determined from the equation for the normal distribution given earlier and the parameters given in Table 3-4. The probability that a CAS will consider a second CAS to be within 600 feet as a function of the true altitude difference between the aircraft is given by

$$P_1\ (\hat{H}_{CAS} < 600)$$

where

$\hat{H}_{CAS}$ = altitude difference measured by the CAS

The above expression is related to the error distribution as follows. The error (ε) is related to the true altitude difference (H_T) by

$$\varepsilon = H_T - \hat{H}_{CAS}$$

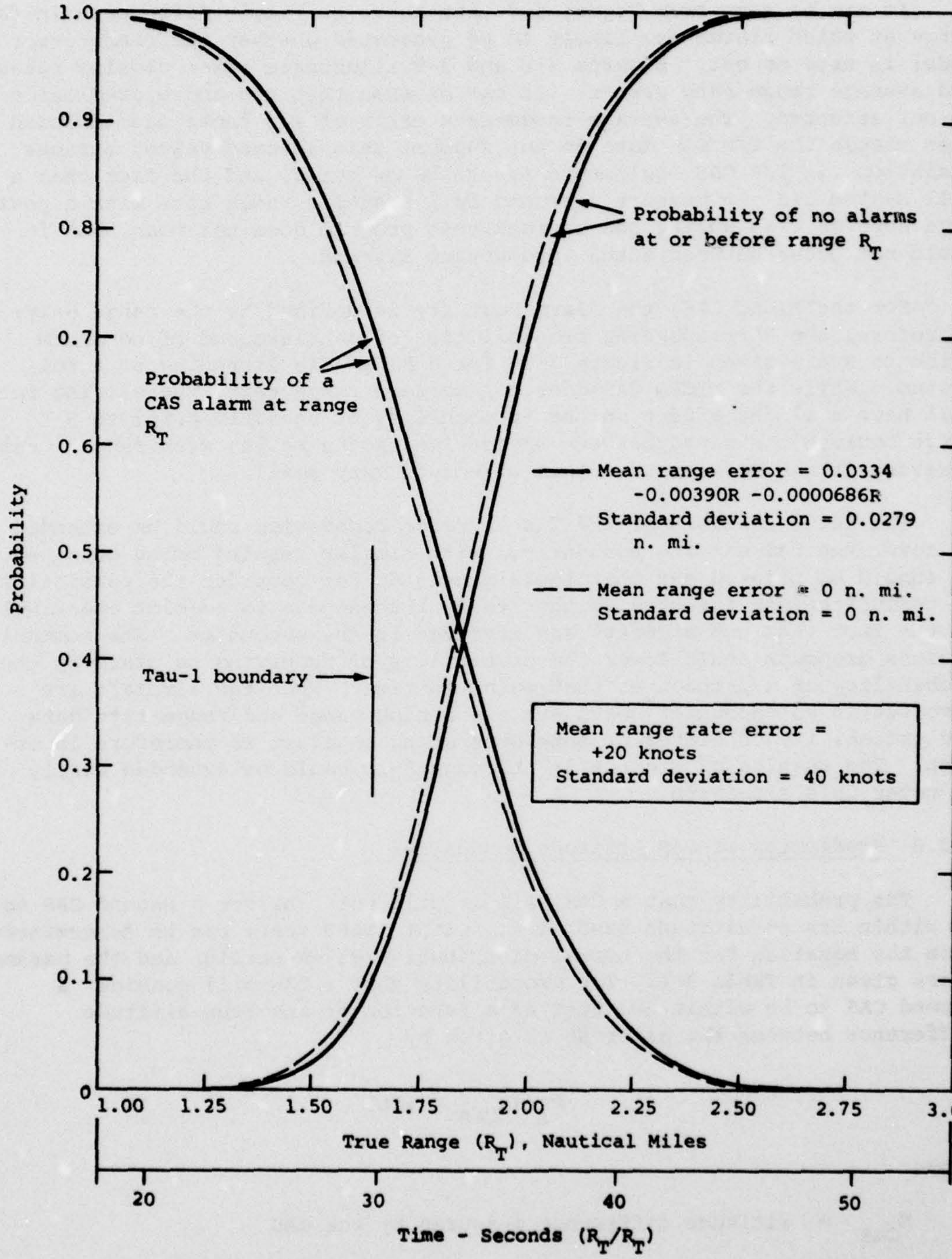

Figure 3-8. **PROBABILITY OF FULL CAS ALARMS FOR A TRUE RANGE RATE OF 200 KNOTS**

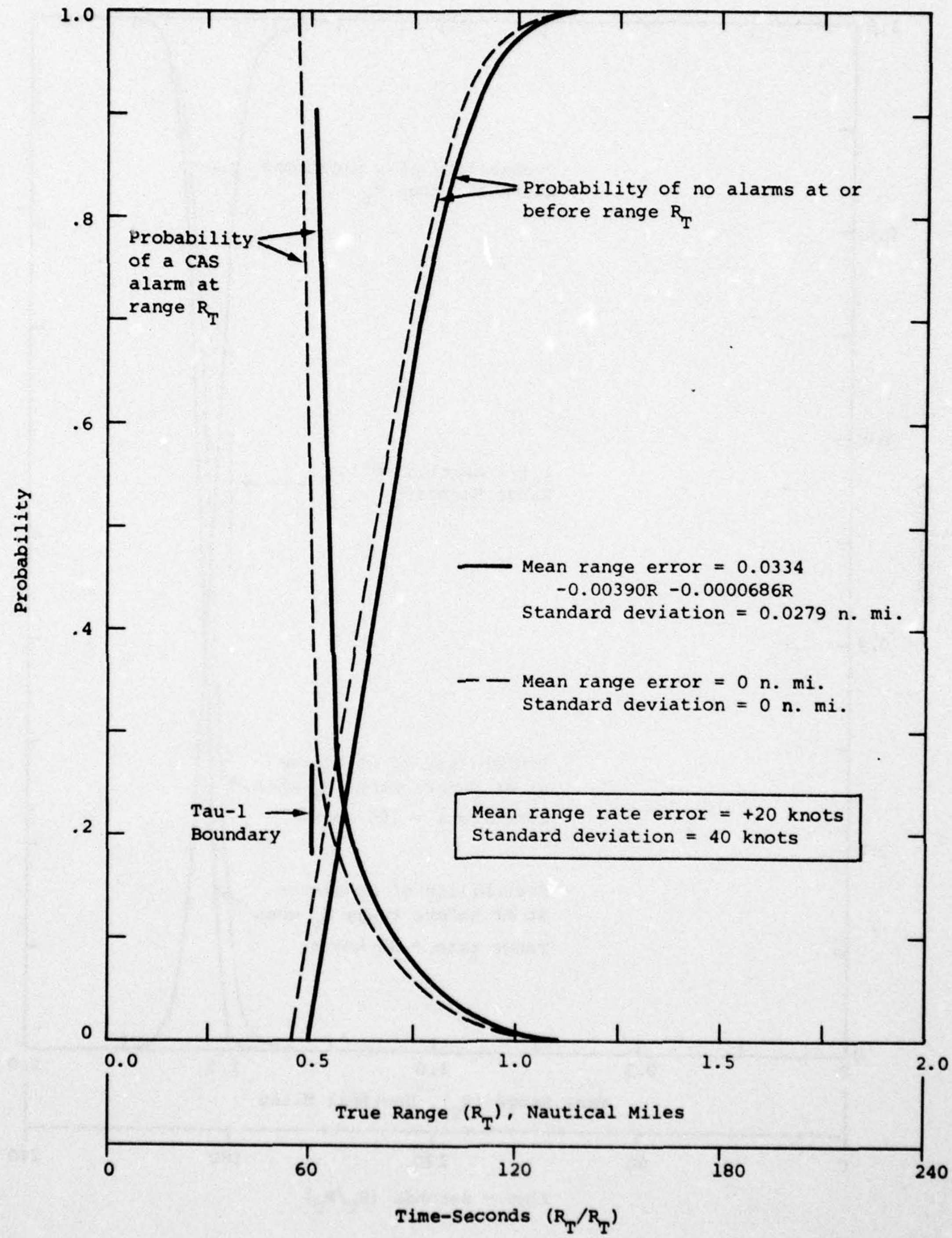

Figure 3-9. **PROBABILITY OF FULL CAS ALARMS FOR A TRUE RANGE RATE AND A DIFFERENT MEAN RANGE RATE ERROR OF 30 KNOTS**

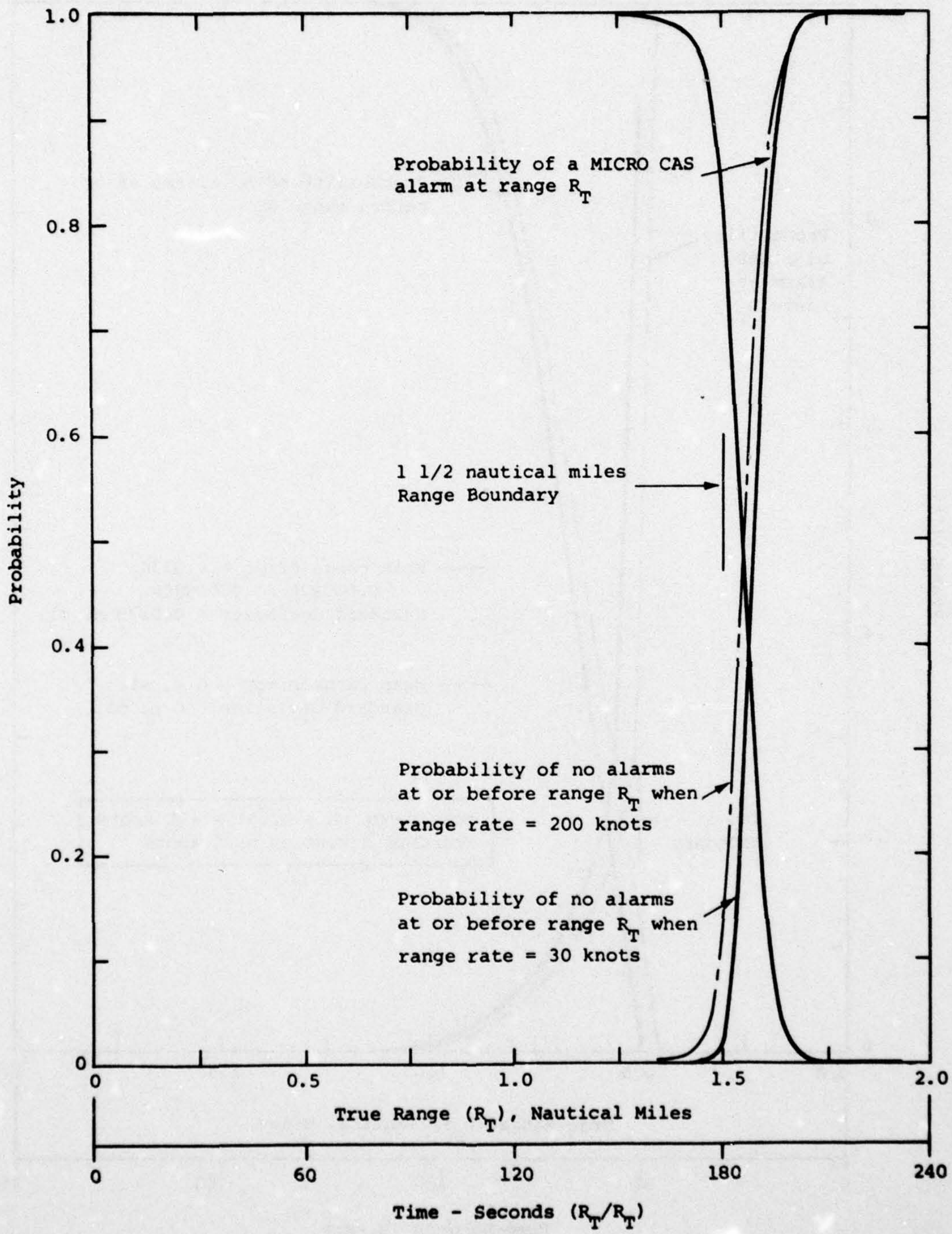

Figure 3-10. THREAT BOUNDARY FOR A MICRO CAS LISTENING TO A FULL CAS

Therefore,

$$P_1 \; (\hat{H}_{CAS} < 600) \;=\; P_1 \; [(H_T - \varepsilon) < 600]$$

$$P_1 \; (\varepsilon > H_T - 600) \;=\; \int_{H_T}^{\infty} P(\varepsilon) \; d\varepsilon$$

where $P(\varepsilon)$ is the normal probability distribution. The last of the above equations can be evaluated for various values of H_T.

Figures 3-11, 3-12, and 3-13 show the probability that a CAS will consider an intruder to be within 600 feet as a function of the true altitude difference for three CAS equipment combinations. The distributions are discontinuous and emphasize the fact that the basic source of altitude data used by the CAS (i.e., the ATCRBS encoding altimeter) has 100-foot granularity. Even in the worst case, Figure 3-13, there is a high probability that the CAS will consider the intruder to be a threat if the true altitude difference is less than 400 feet and a low probability if the true altitude difference is greater than 900 feet.

3.4 ANALYSIS OF CAS ALARMS GENERATED DURING THE FLIGHT-TEST PROGRAM

An evaluation of the times that CAS alarms were generated was never a major objective of the flight-test program. The most important objective of the test program was considered to be the development of appropriate models of the performance of the T/F CAS concept. Therefore, the encounter patterns were designed to be flown with the aircraft intentionally not following the CAS alarms*. It was considered important not to tailor the flight profiles too closely to the threat logic incorporated in the T/F CAS units under test because the threat logic could be changed for reasons not related to the T/F CAS concept. Such a change should not affect the flight-test results. Nevertheless, a record was made of all CAS-generated warnings and alarms. These data have been used as a check on the ability of the CAS to determine the penetration of a threat boundary during the two-aircraft-encounter missions and the traffic-pattern tests.

3.4.1 Warnings and Alarms During Two-Aircraft-Encounter Missions

The threat data for selected missions are presented in Figures 3-14, 3-15, and 3-16. Only data from selected missions were included in the

* Compliance with the pre-planned positive altitude separations designed to provide aircraft safety was ensured by altimeter calibration in formation flight prior to each set of encounters. The ground tracking system allowed the vector controller to assist the pilots in determining the safety as specified in the flight-safety portion of each pre-mission briefing (see Appendix B).

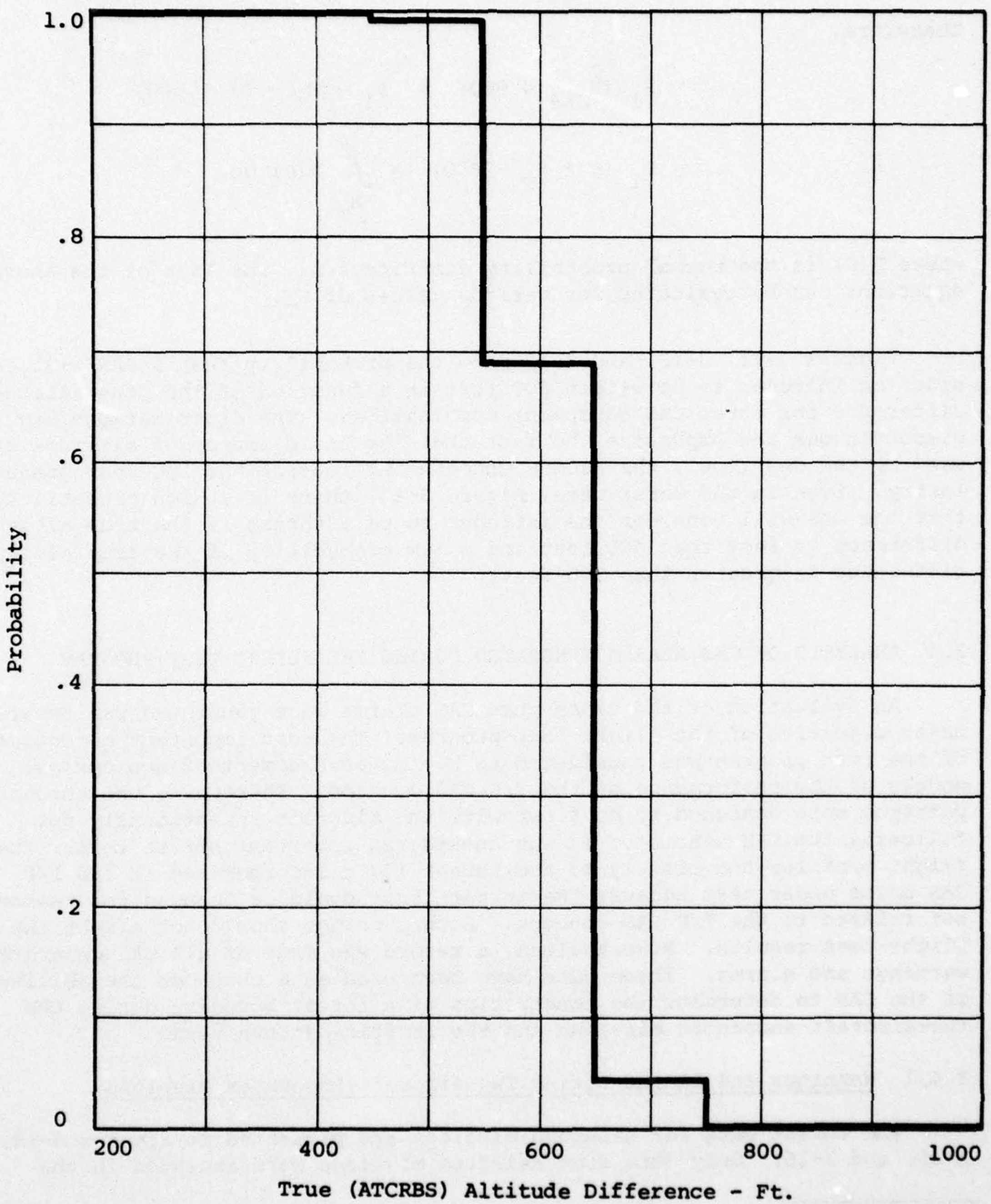

Figure 3-11. **PROBABILITY A FULL CAS WILL CONSIDER A SECOND FULL CAS TO BE WITHIN 600 FT AS A FUNCTION OF TRUE ALTITUDE DIFFERENCE**

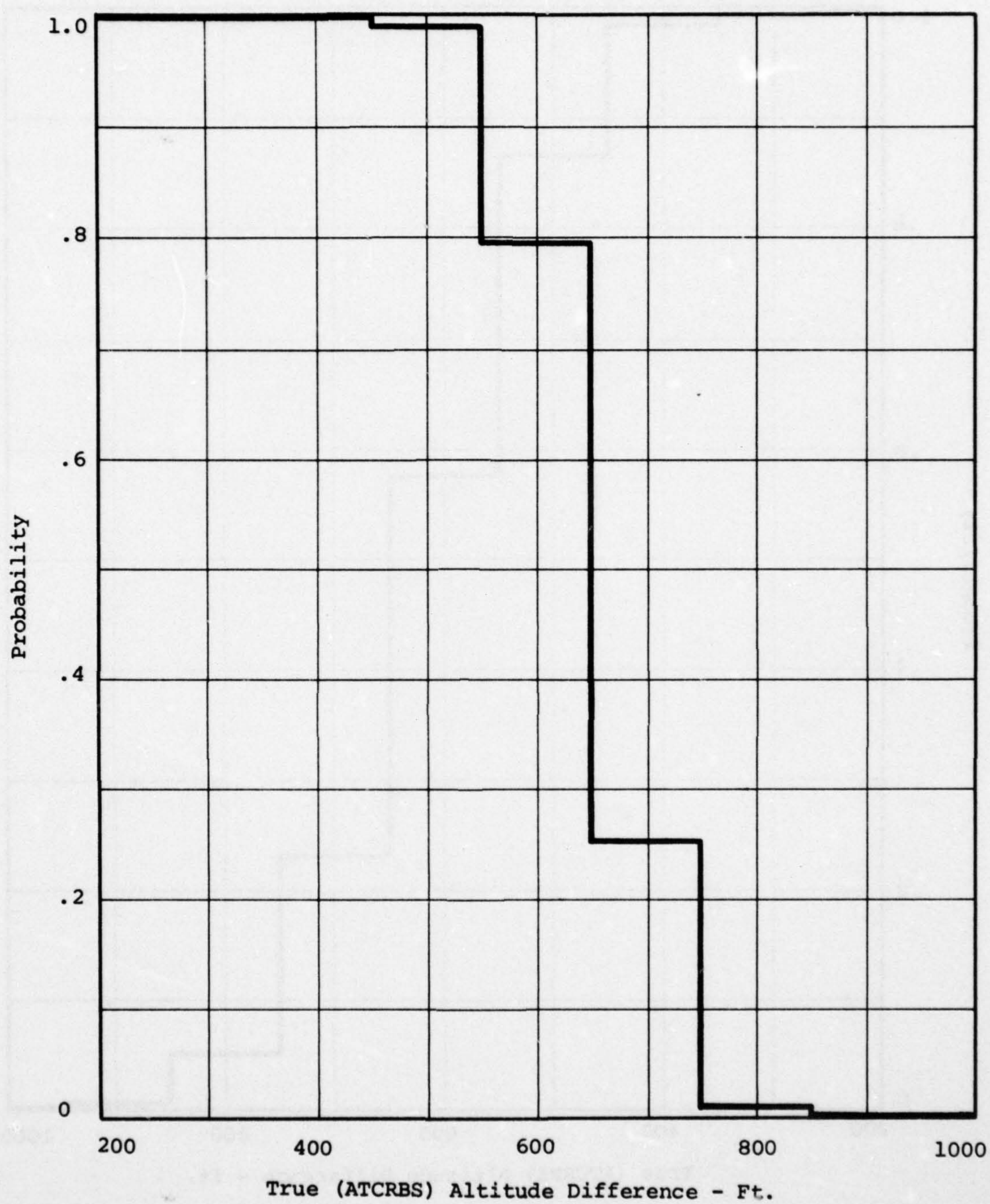

Figure 3-12. **PROBABILITY A FULL CAS WILL CONSIDER A MICRO CAS TO BE WITHIN 600 FT AS A FUNCTION OF THE TRUE ALTITUDE DIFFERENCE**

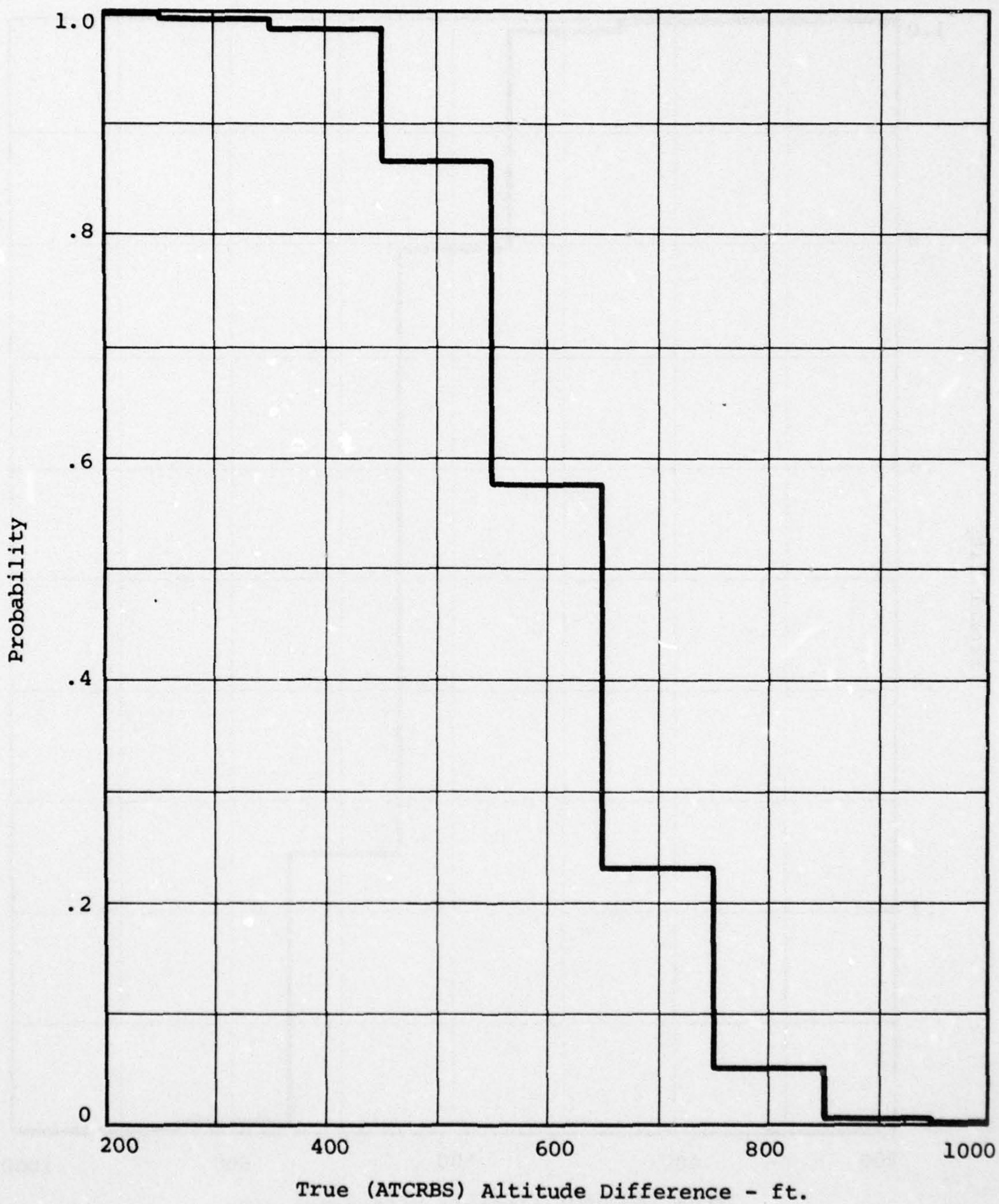

Figure 3-13. PROBABILITY A MICRO CAS WILL CONSIDER A SECOND MICRO CAS TO BE WITHIN 600 FT AS A FUNCTION OF THE TRUE ALTITUDE DIFFERENCE

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TEST AND EVALUATION OF THE TIME/FREQUENCY COLLISION AVOIDANCE S--ETC(U)
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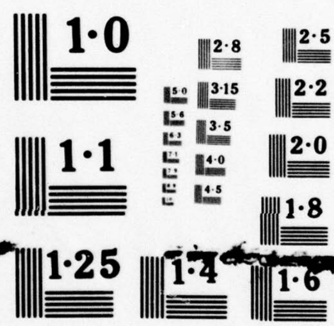


NATIONAL BUREAU OF STANDARDS
MICROCOPY RESOLUTION TEST CHART

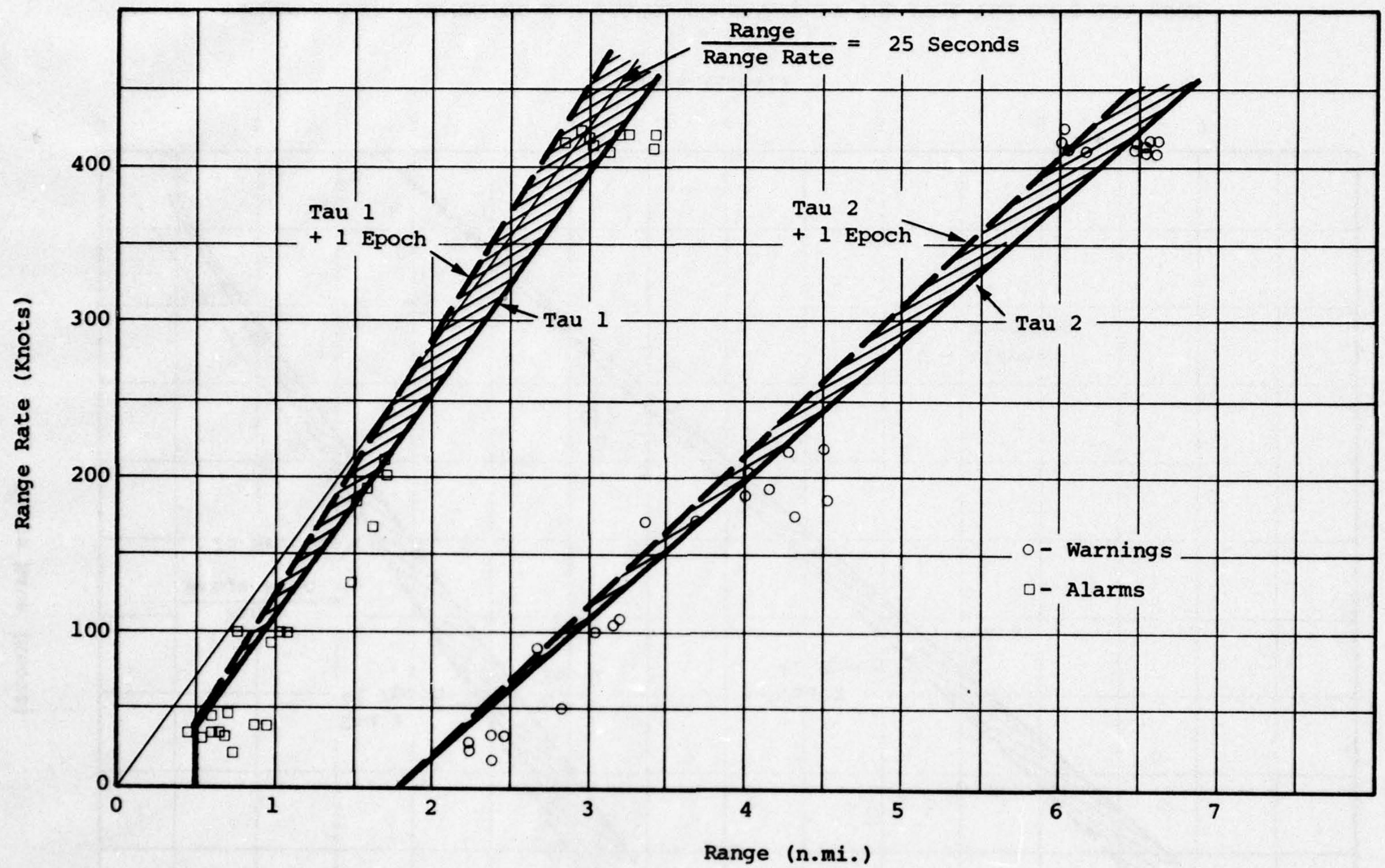


Figure 3-14. WARNINGS AND ALARMS GENERATED BY THE FULL CAS ON C-131 #819

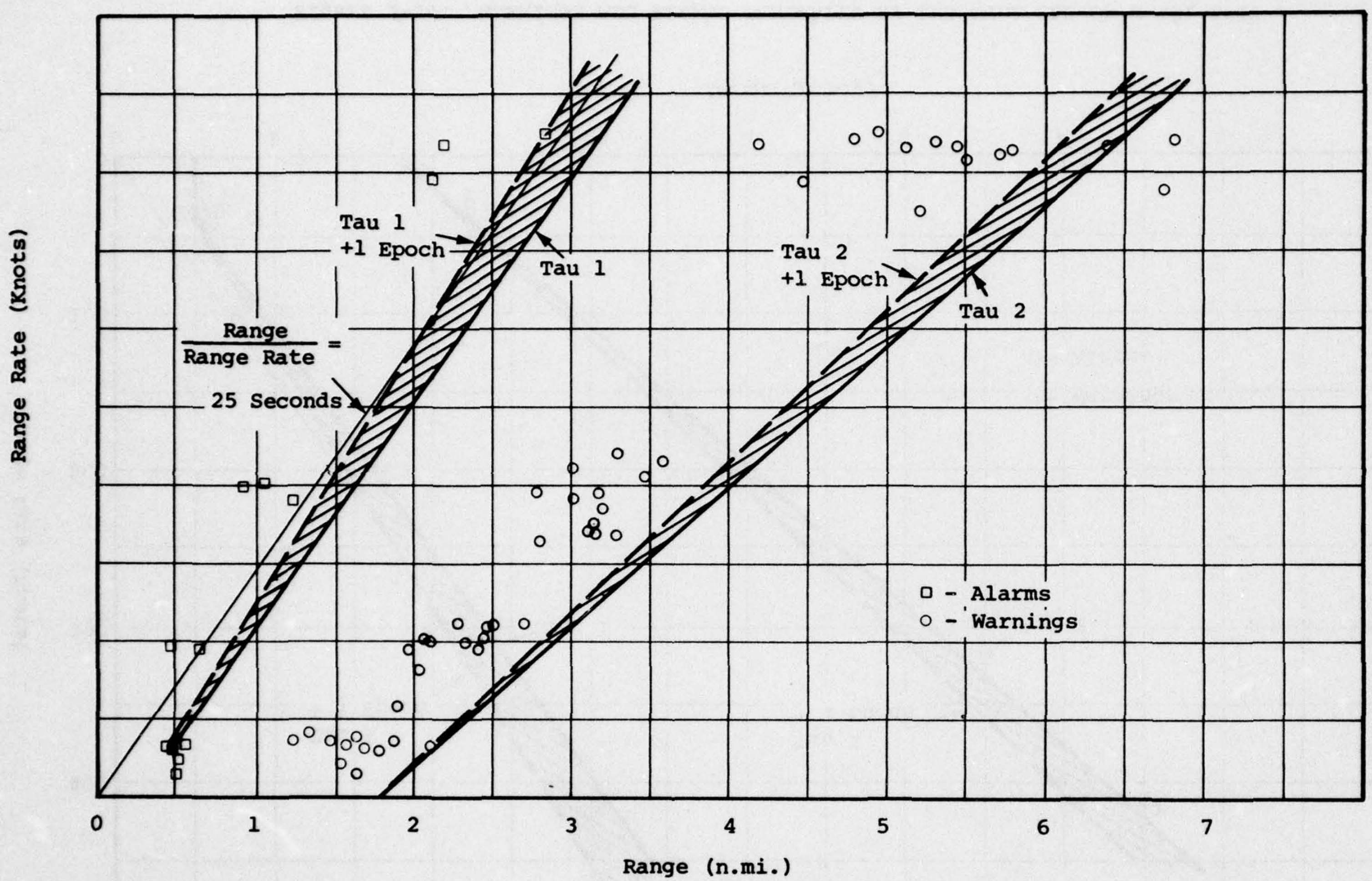


Figure 3-15. WARNINGS AND ALARMS GENERATED BY THE FULL CAS ON C-131 #804

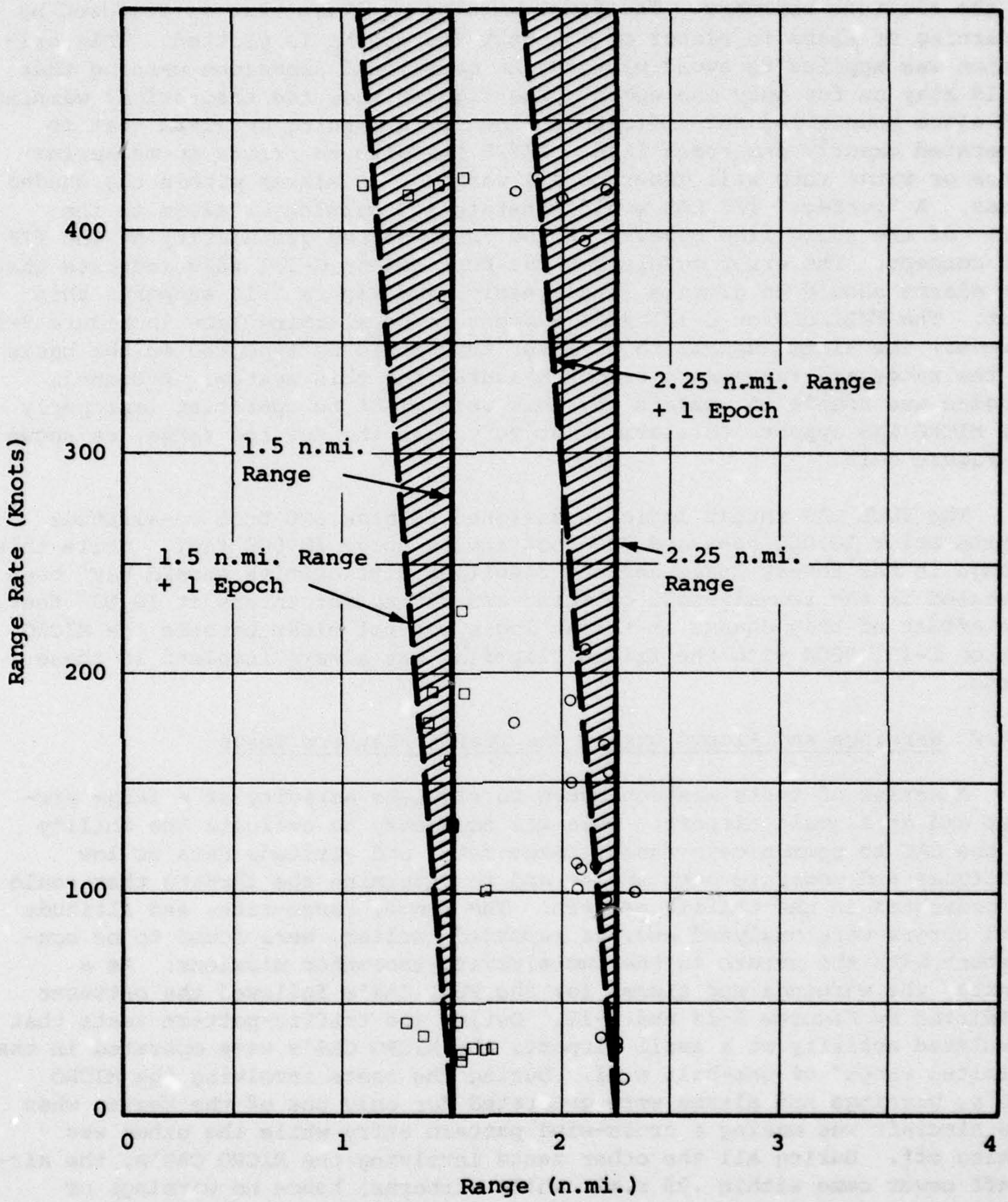


Figure 3-16. WARNINGS AND ALARMS GENERATED BY THE MICRO CAS

figures to avoid the problem of delayed alarms due to the late penetration of the altitude boundary. The first warning or alarm that is followed by a warning or alarm in either of the next two epochs is plotted. This criterion was applied to avoid plotting an occasional anomalous warning that would stay on for only one epoch. The figures show the theoretical warning and alarm boundaries and indicate a line for a warning or alarm that is generated exactly one epoch late. A T/F CAS with no errors in measuring range or range rate will generate all warnings or alarms within the shaded areas. A "perfect" T/F CAS would generate its warning or alarm to the left of the solid line because of the three-second granularity of the T/F CAS concept. The error models for the FULL CAS on C-131 #819 indicate that the alarms should be given a little early, and Figure 3-14 supports this fact. The FULL CAS on C-131 #804 appears to be alarming late in Figure 3-15. However, the alarms appear to be later than would be expected on the basis of the range and range-rate errors measured for this system. McDonnell Douglas was unable to explain why this unit might be operating improperly. The MICRO CAS appears to alarm at or very near the desired range, as shown in Figure 3-16.

The FULL CAS threat logic is designed to have 600-foot co-altitude limits below 10,000 feet and 800-foot limits above 10,000 feet. While this change in the threat logic and any resulting difficulties should have been revealed in the two-aircraft climbing and diving encounters at 10,000 feet, the effect of this change in threat logic was not clear because the MICRO CAS on C-131 #804 with the failed flip-flop was always involved in these tests.

3.4.2 Warnings and Alarms During the Traffic-Pattern Tests

A series of tests was conducted to simulate activity at a large airport and at a small airport. This was necessary to evaluate the ability of the CAS to communicate range, range-rate, and altitude data at low altitudes and moderate bank angles and to determine the threats that could be generated in the traffic pattern. The range, range-rate, and altitude data errors were analyzed and, as reported earlier, were found to be consistent with the errors in the two-aircraft-encounter missions. As a result, the warnings and alarms for the FULL CAS's followed the patterns predicted by Figures 3-14 and 3-15. During the traffic-pattern tests that simulated activity at a small airport, the MICRO CAS's were operated in the "limited range" of one-half n.mi. During the tests involving the MICRO CAS's, warnings and alarms were generated for only one of the tests, when one aircraft was making a cross-wind pattern entry while the other was taking off. During all the other tests involving the MICRO CAS's, the aircraft never came within .95 n.mi. while airborne; hence no warnings or alarms were to be expected. The single alarm that was generated was caused by an altitude reading error of 100 feet by the MICRO CAS on C-131 #819. The alarm was a dive command to an aircraft immediately after take off -- which is not a favorable time for a dive maneuver. This demonstrates the need to withhold dive commands to an aircraft until it is at a safe altitude. This should force the upper aircraft to climb.

The tests involving the FULL CAS units generated warnings and occasionally generated alarms. The warnings were early for the FULL CAS on C-131 #819 and late for FULL CAS on C-131 #804, as would be expected from Figures 3-14 and 3-15. CAS alarms were generated during the simulated approach to parallel runways and during one of the simulated approaches to intersecting runways. The alarm generated during the simulated approach to intersecting runways occurred after the approaches were broken off. However, the alarms generated during the approach to parallel runways occurred when the aircraft were on final. The approach was flown such that the aircraft were separated by more than .55 n.mi. Therefore, the CAS's were not alarming because the one-half n.mi. minimum range criterion was violated, but because of inaccuracies in the range-rate measurement. The range and range-rate error models predict the alarms observed during this test. It would seem that the current CAS threat logic and range-rate measurement accuracies are incompatible with operations at parallel runways separated by one-half mile.

The traffic-pattern tests demonstrated that the CAS equipments will not generate an abundance of alarms when aircraft are in the traffic pattern. However, closely spaced parallel runways present a special case in which a CAS alarm can be expected to occur. Also, there is a need to inhibit dive commands to a very-low-flying aircraft and force the upper aircraft to climb, instead.

3.5 COMMUNICATIONS RELIABILITY

The accuracy with which a T/F CAS can measure range, range rate, and altitude is only a part of the overall evaluation of the effectiveness of a CAS concept. The reliability of communications between systems is very important because if communications reliability is low, the chances of detecting a threatening aircraft are reduced.

Communications reliability was determined by checking for proper reception of some 18,500 transmissions during the two-aircraft-encounter test. The synchronization, supersonic, and BUM test communications reliabilities are not considered here but are treated elsewhere in this chapter. The MICRO CAS tests for time-slot co-occupants by periodically not transmitting in its own time slot. The data dropouts due to these nontransmissions were identified and deleted from the analysis because it was desired to determine the frequency of failure of the CAS receivers to detect and/or accept transmissions and to identify any relationships that exist between communications failures and range, altitude, relative position, closure rate, etc. The frequency of occurrence and the pattern for nontransmission by the MICRO CAS were determined and evaluated for effect on system operation. Since the FULL CAS transmits in an alternate time slot when it listens for a co-occupant in its own time slot, the frequency and pattern of the checks for co-occupancy do not affect communications, but the frequency and pattern were determined for comparison with the MICRO CAS. The communications reliability was very much higher when the receiver was a MICRO CAS; the antenna switching used by the FULL CAS was examined and was

found to be responsible. The effect of the AN/APN-159A radar altimeter on communications reliability during the flight program was determined. The effect of the AN/APN-159A radar altimeter is also discussed in Chapter Four.

3.5.1 Communications Reliability Percentages

The percentages of communications failures for various combinations of transmitter and receiver are shown in Table 3-5. The data are broken down by altitude, and the data obtained in the tests with the AN/APN-159A radar altimeter are included for comparison. The radar altimeter will be discussed in another subsection. The only comment made here is that it very greatly reduced communications reliability on the aircraft in which it was installed and caused smaller but still appreciable reduction in communications reliability on the other aircraft, which occurred only at the short ranges.

Table 3-5. CAS COMMUNICATION RELIABILITY FOR VARIOUS LINKS AND CONDITIONS

System Combinations	Percentage of Communication Failures						
	Without Radar Altimeter			AN/APN-159A on Receiving Aircraft		AN/APN-159A on Transmitting Aircraft	
	10,000 Feet Altitude	2,000 Feet Altitude	10,000' & 2,000' Altitude	10,000 Feet Altitude	2,000 Feet Altitude	10,000 Feet Altitude	2,000 Feet Altitude
MICRO Receiving MICRO	0.26	1.13	0.64	12.82	6.15		2.22
MICRO Receiving FULL	0.82	1.30	1.14			0.89	
FULL Receiving MICRO	1.96	4.09	3.21	50.58	15.59	5.36	10.85
FULL Receiving FULL	3.50	6.17	5.42	34.71	18.03		
Combined MICRO Receiving	0.36	1.19	0.78				
Combined FULL Receiving	2.26	4.79	3.76				

The communications reliability of the T/F CAS equipments was quite high. The highest rejection rate for the FULL CAS was 6.17 percent and for the MICRO CAS 1.3 percent. These levels of communications reliability are considered completely satisfactory for the purpose of detecting and evaluating collision threats.

The rejection rate of the FULL CAS was always found to be higher than that of the MICRO CAS. The overall rejection rate of the MICRO CAS was

0.78 percent, and the rejection rate of the FULL CAS was about five times higher, 3.76 percent. The difference in performance was found to be caused by the antenna switching used by the FULL CAS, which will be discussed later, and by the more rigorous range and altitude pulse-verification logic in the FULL CAS.

It was found that the rejection rate at the low altitude (1,500 to 2,000 feet) was approximately twice the rejection rate at the high altitude (9,000 to 10,000 feet). For the MICRO CAS there were too few rejections to be able to identify clearly any relationship between rejection rate and range between the aircraft; however, the distribution seemed to indicate that rejections are independent of range out to ranges of 15 to 20 nautical miles.

The rejection rate for MICRO CAS receiving from another MICRO CAS is lower than the rejection rate for MICRO CAS receiving from a FULL CAS, and this shows that use of the lower antenna by a FULL CAS for transmission also adversely affects communications reliability. This conclusion is substantiated by the fact that the FULL CAS has a higher rejection rate when receiving from another FULL CAS than when receiving from a MICRO CAS. The effect of antenna switching for transmission is small when compared with the effect of antenna switching for reception; however, this effect was also further analyzed.

3.5.2 Effect of Antenna Switching on Communications Reliability

During "ground" epochs the FULL CAS listens on the upper antenna for intruder transmissions but transmits its own message on the lower antenna. During "air" epochs the procedure is reversed, with the lower antenna receiving intruder transmissions and the upper antenna transmitting its own message. As a result of the much larger signal-rejection rate of the FULL CAS, the antenna-switching process was examined as the most likely cause. More than 5,000 epochs were examined, which included operation at 2,000 feet and at 10,000 feet both with and without the radar altimeter operating on one aircraft.

For the FULL CAS as receiver, there were a total of 154 signal rejections, of which 134 were rejected from the lower antenna and 20 were rejected from the upper antenna. Without the radar altimeter operating, there were 107 signal rejections from the lower antenna and 11 rejections from the upper antenna. Thus 90.67% of the rejections were from the lower antenna. In operations at 2,000-feet altitude, the rejections were evenly distributed in range except that at very short range, where the transmitting aircraft was nearly straight above, the number of rejections was approximately double. In operations at 10,000 feet, rejections occurred at the longer

ranges, with 75% occurring at seven nautical miles and beyond. In operations at 2,000 feet with the radar altimeter also operating, there were 17 signal rejections, 11 of them occurring at less than one-mile range and the remaining six scattered as single occurrences at six ranges. The rejections were almost equally divided between the antennas, with ten from the lower and seven from the upper. The concentration of rejects at short ranges and the almost equal distribution between upper and lower antennas indicate that direct radiation into the upper antenna was significant as the radar-altimeter aircraft flew nearly directly overhead. In operations at high altitude with the radar altimeter also operating, the signal rejections were equally distributed up to three miles range but the lower-antenna rejections totaled 16, while there were only two upper-antenna rejections. This would indicate that the radar-altimeter interference was almost entirely via reflected signals into the lower antenna, but the data sample is considered too small for a positive conclusion.

The analysis of antenna switching by a FULL CAS when a MICRO CAS is the receiver proved inconclusive because the high communications reliability of the MICRO CAS resulted in too few data points to be statistically significant. There were only 24 signal rejections, and they were almost equally divided between transmissions coming from the upper antenna and transmissions coming from the lower antenna.

3.5.3 Effective Reductions in Communications Reliability Due to MICRO CAS Tests for Co-Occupancy

In testing for time-slot co-occupancy, the MICRO CAS inhibits transmission and instead listens for another system transmitting in that time slot. These non-transmit epochs have the same effect as communications dropouts in that the other aircraft obtain no information during that epoch. Therefore, the pattern of testing for co-occupants was analyzed. The test sample included more than 3000 epochs and 379 co-occupancy tests. It was found that the MICRO CAS pattern of testing is approximately an exponential distribution. The pattern is shown in Figure 3-17. It shows the number of epochs between tests versus the number of occurrences of each of the values. The mean value of the number of epochs between tests is 8.21, which at three seconds per epoch, is 24 seconds between tests. The distribution is heavily weighted at the smaller values, which indicates that the tests for co-occupancy occur in bursts of several tests within a few epochs separated by long runs of no tests. A frequently observed pattern was two consecutive tests, one transmission, another test, and then a run of from 12 to 20 epochs with no tests. The observed pattern is undesirable because it increases the probability that threat detection will be delayed because of inhibiting transmission as the threat boundary is being crossed. The mean value of 8.21 epochs between tests means that the MICRO CAS inhibits transmission in 12.18% of the epochs. When this loss of communications opportunities is added to the signal-rejection rate, the communications

reliability approaches marginal values. However, it does not alter communications reliability after a threat has been detected because testing for co-occupants is inhibited while the threat exists.

The pattern of testing for co-occupancy by the full systems was determined so that it could be compared with the pattern of the MICRO CAS. Testing for co-occupancy by the full system does not affect communications reliability because the full system transmits in an alternate time slot when it listens for a co-occupant in its own time slot. The distribution of testing by the full system is shown in Figure 3-18. The mean value is 17.07 epochs between tests, which, at three seconds per epoch, is 51 seconds between tests. This distribution is also exponential, with heavy weighting at the smaller values, but in this case the smallest observed number of epochs between tests was ten. This pattern is more satisfactory than is the pattern of the MICRO CAS; however, it is suggested that the logic that generates the pattern should be designed for a maximum value of 20 epochs, i.e., one minute, between tests.

3.5.4 Effect of AN/APN-159A Radar Altimeter on Communications Reliability

The AN/APN-159A radar-altimeter transmission consists of 0.8-microsecond pulses at 1621 MHz. These pulses have enough bandwidth to be detectable in all four CAS frequencies -- 1600, 1605, 1610, and 1615 MHz. The pulses are too narrow to interfere with CAS operation by causing apparently occupied slots since the minimum pulse width that will be treated as a CAS signal is 8 microseconds. However, the sharp increase in signal rejections, shown in Table 3-5 that took place when the AN/APN-159A was operated demonstrated that the CAS's were experiencing interference from the radar-altimeter transmissions. The mechanism of the interference is apparently a distortion of the received CAS signals to the extent that they do not pass the acceptance criteria. The high rejection rates of the CAS equipments in the same aircraft as the radar altimeter show that the T/F CAS and the radar altimeter are incompatible when installed in the same aircraft. The overall rejection rate on the aircraft that did not have the radar altimeter was increased by a factor of 2.5. This, coupled with the fact that the majority of these rejections occurred at the shorter ranges, shows that the radar altimeter has an unacceptable level of interference with T/F CAS communications to other aircraft. The reversal of the rejection rates of the full system when it is receiving a MICRO CAS, as opposed to when it is receiving a full system, indicates that the stronger signal from the FULL CAS is less susceptible to interference but not sufficiently less susceptible for satisfactory operation.

The in-flight experience with the AN/APN-159A and the laboratory tests of the AN/APN-155B, as reported in Chapter Four, show that the frequency bands used for collision avoidance must be kept clear of RF energy from equipments operating in adjacent frequency bands.

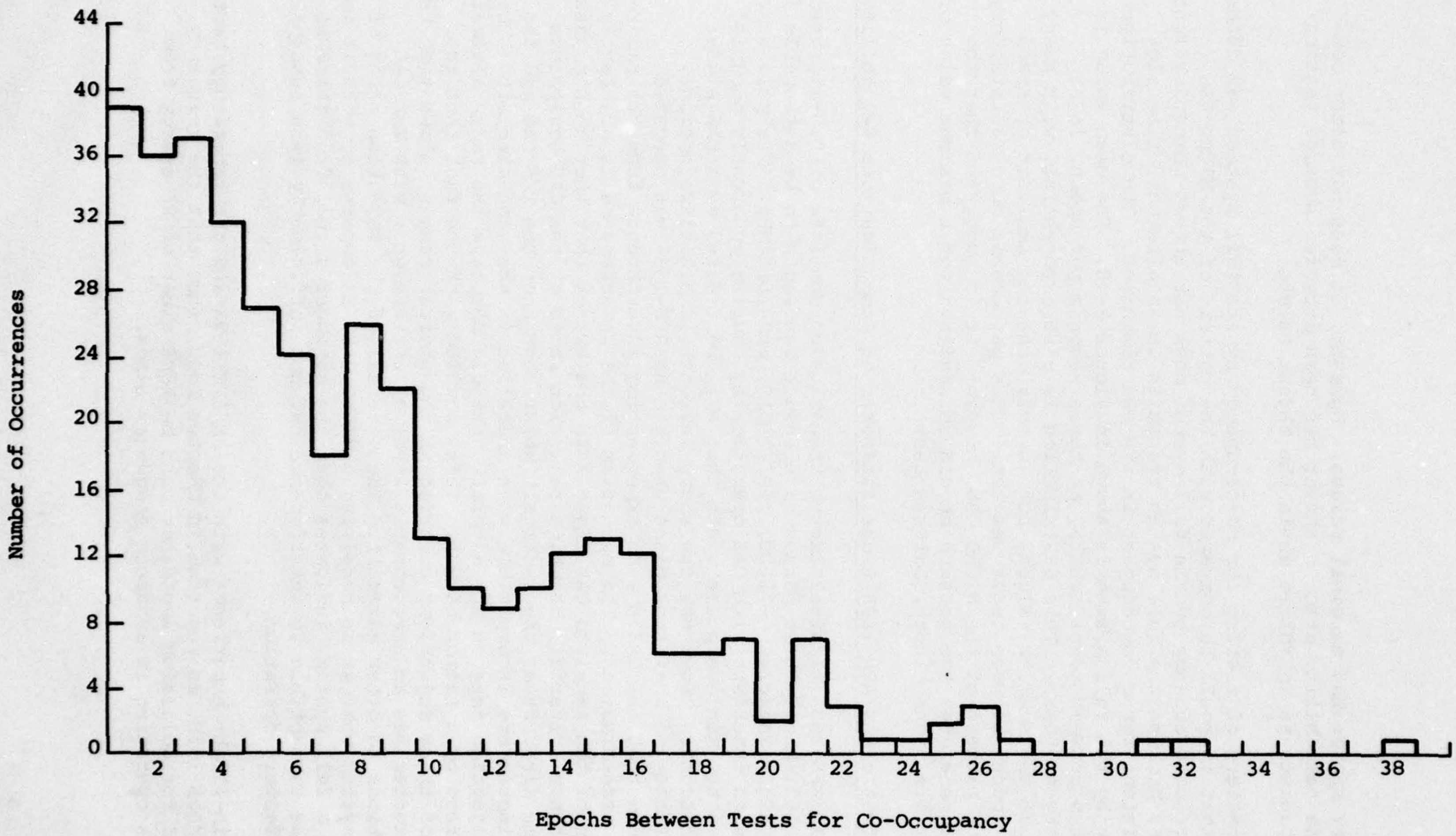


Figure 3-17. MICRO CAS TESTS FOR CO-OCCUPANCY

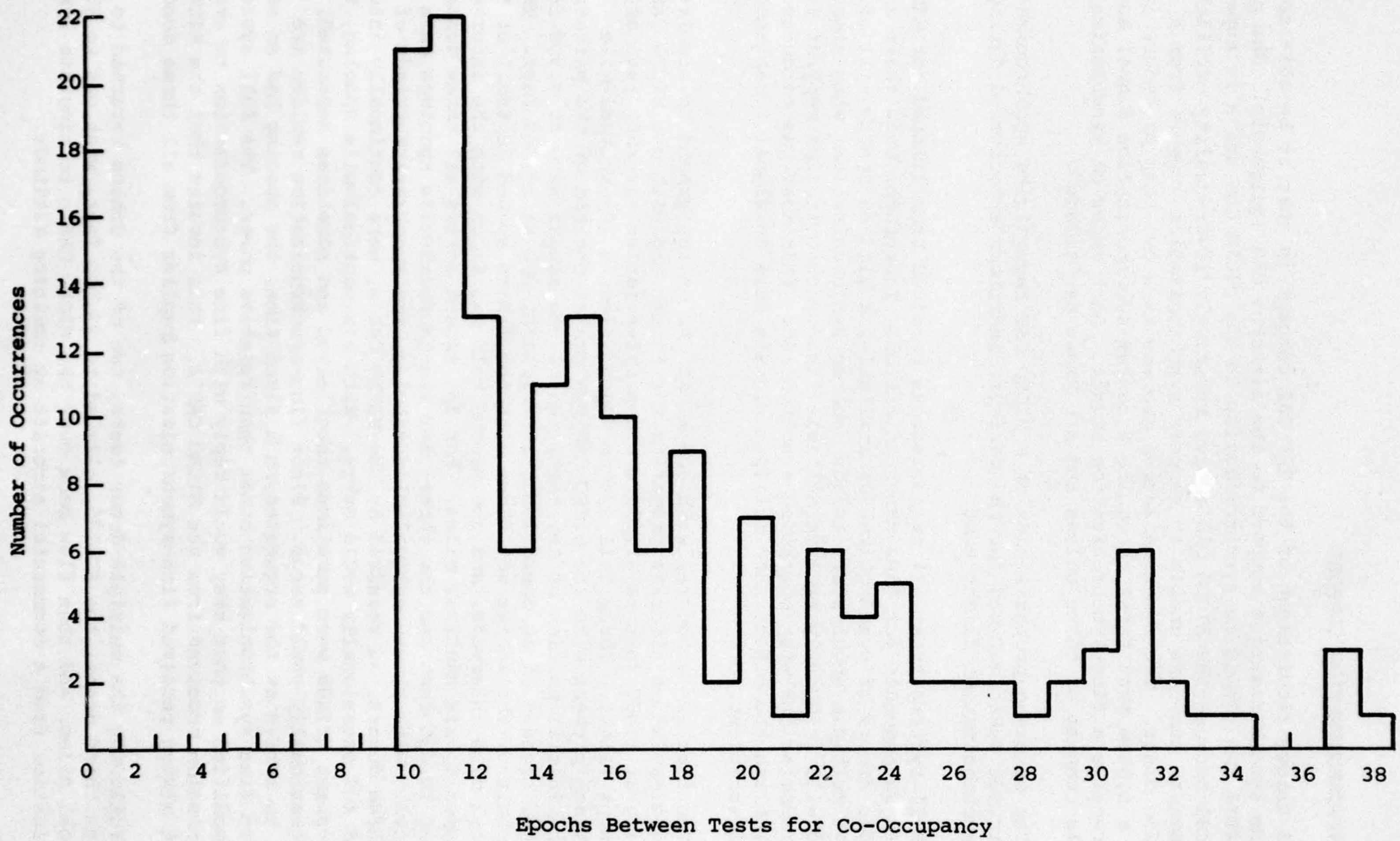


Figure 3-18. FULL CAS TESTS FOR CO-OCCUPANCY

3.6 SYNCHRONIZATION SUPPORT

A unique requirement of the T/F CAS concept is that it be able to provide synchronization support to the airborne CAS equipments. The process of a FULL CAS providing synchronization to the MICRO CAS units is especially critical because the MICRO CAS's have relatively lower-quality oscillators and because they are unable to request synchronization support from a specific donor. The synchronization process is a two-step procedure in which a system must first recognize a coarse-synchronization signal and then receive a fine-synchronization signal. Both types of synchronization signals consist of three pulses and are known as "triads".

The observed probabilities of a MICRO CAS recognizing synchronization triads were analyzed for the various conditions encountered during the synchronization flight test.

Full systems treat all transmissions received from limited (or MICRO) systems as requests for fine synchronization. Therefore, when there are multiple donors of synchronization available, a limited system will always receive multiple epoch-start triads (coarse synchronization) when starting up and will frequently receive multiple fine-synchronization replies to its transmissions when operating synchronized. This test was conducted to establish the effect such multiple signals have on signal acceptance by the recipient.

The test was conducted with one MICRO CAS on the ground to simulate a general-aviation aircraft preparing for flight and with one MICRO CAS orbiting at 1,000 feet to simulate a general-aviation aircraft just after beginning flight. Three full system donors flew a 20-nautical-mile race-track pattern with the MICRO CAS systems at one end of the pattern. For the initial portion of the test, two of the donors were at 4,500 feet and one, because of an operational restriction, was at 10,000 feet. The first half of the series was flown with the donors spaced in trail at three-nautical mile intervals, and the second half was flown with the interval increased to six nautical miles. For the second series all three donors were at 10,000 feet and the three- and six-nautical-mile spacings were repeated. With three-nautical-mile spacing, the epoch-start triads of the three donors, as received by the MICRO CAS's, were continually interleaved and occasionally would merge. With six-nautical-mile spacing, the epoch-start triads were sometimes interleaved and sometimes separated, and occasionally would merge. Since fine-synchronization replies are timed to arrive at the requester at a fixed time, the spacing had no effect on fine synchronization other than relative power. The full systems were modified so that they would reply with fine synchronization to every transmission received from the MICRO CAS's. This insured that the MICRO CAS's almost always received fine-synchronization replies from all three donors.

Following the multiple-donor tests, two of the donors returned to base and the third donor, the KC-135, climbed to 35,000 feet, went out to 55 nautical miles, and then flew back over the MICRO CAS's to simulate synchronization from a commercial aircraft at cruising altitude.

3.6.1 Results of the Synchronization-Support Tests

For analysis of the test data, the data were separated into air epochs, in which multiple donors were available, and ground epochs, in which only the ground station was available as a donor to the airborne MICRO CAS. The MICRO CAS on the ground was never able to hear the ground station, and the airborne MICRO CAS was below the ground station's horizon part of the time and above it part of the time.

Figure 3-19 consists of graphs of the number of signals recognized by the airborne MICRO CAS in each one-minute interval. Graph "A" is the number of air epoch-start triads accepted from the airborne donors. Graph "B" is the number of ground epoch-start triads accepted from the ground station. Graph "C" is the number of air fine-synchronization replies recognized from the airborne donors. Graph "D" is the number of ground fine-synchronization replies accepted from the ground station.

In Graph "A" the period from zero to 18 minutes shows the effect of interleaved epoch-start triads on signal acceptance. They were accepted only when fully merged, and this condition existed only a small percentage of the time. The motion of the recipient could both aid and hinder the merging. The period from 18 minutes to 37-1/2 minutes shows the increased frequency of acceptance when the spacing permitted the triads to become separated. In the period from 42 1/2 to 64 minutes the triads were again interleaved and the frequency of acceptance again was low. For the four minutes from 52 to 56 minutes the motion of the recipient kept the triads merged to an unusual extent. The period from 65 to 90 minutes was back at 6-nautical-mile spacing, and the frequency of acceptance was again relatively high. At 90 minutes, the C-131 and F-106 aircraft departed and the KC-135 aircraft began climbing to 35,000 feet. The sharp increase in acceptance frequency is due to the loss of interfering transmissions, and it illustrates the reliability of epoch-start recognition when clean signals are available. The drop to zero recognitions in the 97th minute is the result of the banking of the KC-135 when turning to return. At 103 minutes the camera recording the data ran out of film.

Graph "B" shows the effect as the MICRO CAS appeared above and disappeared below the ground station's horizon. This graph is of interest only in comparison with Graph "D", which represents the ground fine-synchronization replies accepted. The comparison shows that the MICRO CAS could recognize the 1000-watt transmissions from the ground station much more often than the ground station could recognize the 200-watt transmissions from the MICRO CAS. It also shows that for limited systems operating near the horizon of a ground station, the ground station cannot reliably provide fine synchronization. If the ground station had been the only donor, the MICRO CAS would probably have gone into standby 13 times and would have spent a cumulative 19 of the 102 minutes in that status.

Graph "C" shows that the multiple fine-synchronization replies caused few signals to be rejected. The reliability of the fine-synchronization process is even higher than is indicated by the graph. Most of the failures

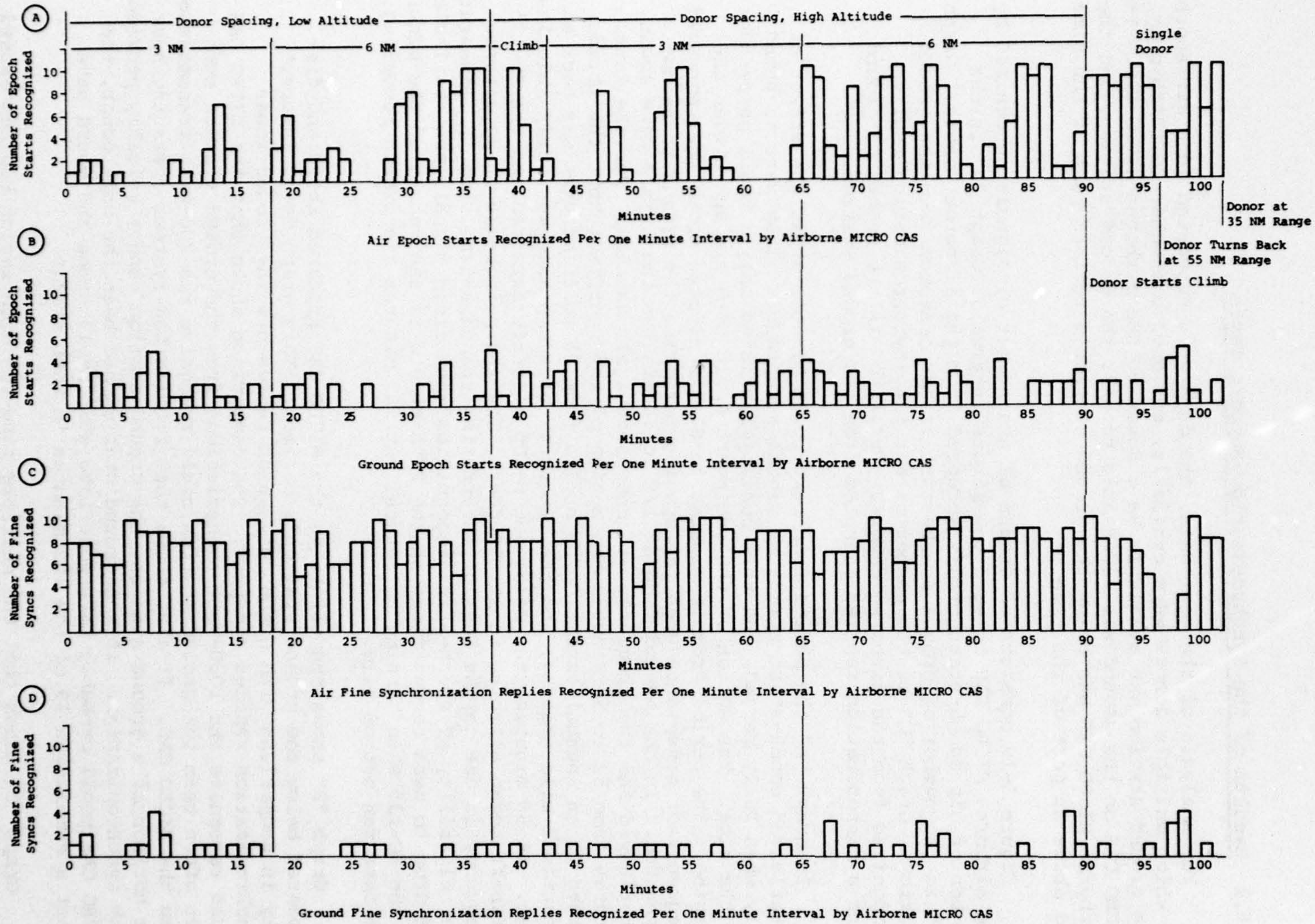


Figure 3-19. AIRBORNE MICRO CAS RECOGNITION OF EPOCH STARTS AND FINE SYNCHRONIZATION REPLIES

to recognize fine-synchronization replies are due to the fact that fine synchronization was not requested due to the MICRO CAS listening for co-occupants instead of transmitting.

Figure 3-20 consists of graphs of epoch-start (or coarse-synchronization) and fine-synchronization acceptance by the MICRO CAS on the ground. The epoch-start recognition, as shown in Graph "A", is very similar to the results obtained by the airborne MICRO CAS, and, as will be shown later, the performances of the two systems were nearly identical. The most important point on this graph is that the epoch-start recognition frequency from a single donor dropped from very high values only when the donor banked to turn back and again when the donor passed overhead. The fine-synchronization recognition frequency, as shown in Graph "B", again shows that multiple fine-synchronization replies had small effect on signal acceptance. The graph shows that the ground MICRO CAS was receiving fine-synchronization replies to every transmission when the donor was at the maximum distance of 55 nautical miles. This indicates that satisfactory fine-synchronization support could have been provided at considerably greater range.

Figure 3-21 is a graph of the combined air and ground fine-synchronization replies accepted by a MICRO CAS during 100 minutes of operation during two other test missions. The first 37 minutes are from a mission at high altitude where communications with the ground station were continuously available. The remaining 63 minutes are from a mission at 2,000 feet in which the ground station was below the horizon part of the time. There were two airborne donors, each of which replied with 50% probability to each transmission received during air epochs from MICRO CAS. Thus there was 25% probability of no reply, 50% probability of only one reply, and 25% probability of two replies. The ground station was replying at 100% to transmissions received during ground epochs. Missed fine synchronizations are due to four causes, listed in decreasing order of importance: (1) non-replies during air epochs, (2) non-requests due to listening for co-occupants, (3) rejected requests, and (4) rejected replies. The graph is not time-continuous, because it is from two missions and because the inordinately large amount of time required to transcribe from the film prohibited collecting data continuously on the photo panels. This graph is included to provide a comparison with the data collected under the special test conditions and to observe the effect when the full systems are providing normal, rather than 100%, fine-synchronization replies.

During the high-altitude portion the MICRO CAS received fine synchronization in 70% of the epochs. If 12% is added to account for the epochs in which the MICRO CAS did not transmit and 12.5% is added to account for the air epochs in which neither of the airborne donors replied, it is found that in only 5.5% of the epochs did the fine-synchronization process fail because of rejected signals. The low-altitude graph was drawn to see if there were any peculiarities that should be looked at more closely. The stair-step effect is the result of the aircraft's coming into, and going out of, the view of the ground station. The sudden drops in minute 56 and minute 82 are time discontinuities; therefore, they do not indicate communications anomalies.

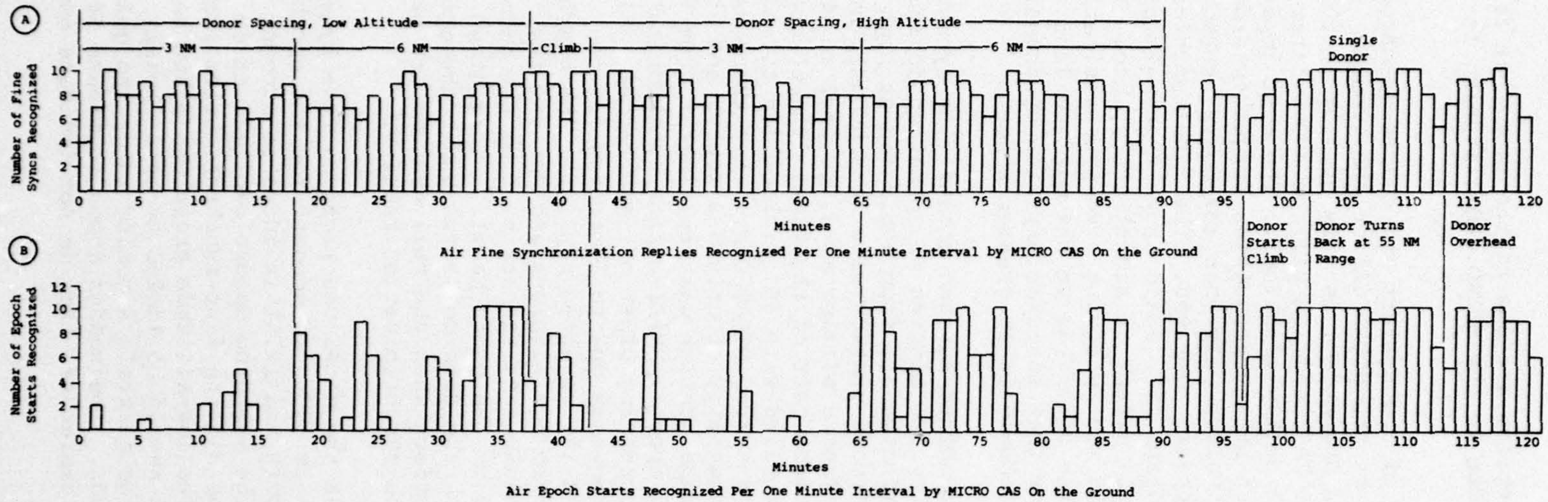


Figure 3-20. RECOGNITION OF FINE SYNCHRONIZATIONS AND EPOCH STARTS BY MICRO CAS ON THE GROUND

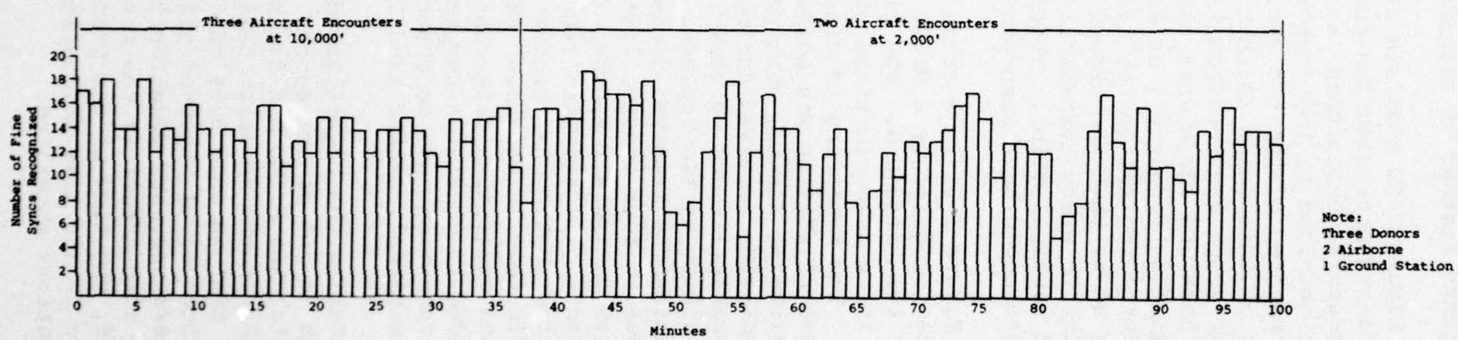


Figure 3-21. NUMBER OF FINE SYNCHRONIZATION REPLIES PER ONE MINUTE INTERVAL UNDER NORMAL CONDITIONS

3.6.2 Statistics of the Test Results

The means and the standard deviations of the signal acceptances during the synchronization test were calculated as shown in the following tables:

Fine Synchronizations Recognized Per Minute						
Test Situation	Multiple Airborne Donors		Single Airborne Donor		Ground Station	
	Mean (Max.=10)	Standard Devia.	Mean (Max.=10)	Standard Devia.	Mean (Max.=10)	Standard Devia.
Airborne MICRO CAS	7.88	1.40	5.83*	3.46	0.61	0.92
Ground MICRO CAS	7.89	1.45	8.00	2.25	N/A	N/A
*Small sample - instrumentation ran out of film.						

The values for the mean and standard deviation of the fine synchronizations recognized from multiple donors show that there was no difference in performance between the airborne system and the ground system. Each system recognized fine synchronization in 79% of the air epochs. If 6% is added to these figures to account for non-requests by the MICRO CAS's in air epochs, the percentages rise to 85%, which leaves 15% as the proportion of rejected fine-synchronization replies. This level of rejection with only three donors shows that the reduced reply rate incorporated in the design of full systems is probably necessary.

Epoch Starts Recognized Per Minute						
Test Situation	Multiple Airborne Donors		Single Airborne Donor		Ground Station	
	Mean (Max.=10)	Standard Devia.	Mean (Max.=10	Standard Devia.	Mean (Max.=10	Standard Devia.
Airborne MICRO CAS	3.37	3.49	7.25	3.14	1.63	1.38
Ground MICRO CAS	3.17	3.64	8.55	2.05	N/A	N/A

Running out of film for the airborne MICRO CAS reduced the data sample for the fine synchronizations recognized from a single donor to a size too small to permit drawing firm conclusions. The performance by the MICRO CAS on the ground was nearly identical with multiple donors and single donors. The concentration of missed fine synchronizations when the donor was climbing and when the donor was turning to return indicates that maneuvers by the donor, with the resulting tilting of the radiation pattern, has an effect almost equal to that of multiple replies on the frequency of obtaining fine synchronization.

The frequency with which the airborne MICRO CAS received fine synchronization from the ground station is again of greatest interest when compared with the frequency with which epoch starts were received from the ground station. The discrepancy between the two mean values indicated that the MICRO CAS recognized transmissions from the ground station approximately twice as often as the ground station recognized transmissions from the MICRO CAS and transmitted fine-synchronization replies. While the ratio of the means is almost three to one, some allowance must be made for the ground epochs in which the MICRO CAS did not transmit.

Epoch-start recognitions from multiple donors by the airborne MICRO CAS and the ground MICRO CAS were nearly identical. The low mean values and high standard deviations indicate that a CAS seeking coarse synchronization when many donors are available could have a delay of several minutes before coarse synchronization is achieved. The high mean values and modest standard deviations of epoch-start recognitions from a single donor indicate that when clean epoch-start triads are available, coarse synchronization will be achieved promptly.

The mean and standard deviation of fine-synchronization recognition during other test missions is included to illustrate the performance that can be expected under normal conditions:

	Mean (Max.=20)	Standard Devia.
Fine Synchronizations Recognized per minute of Normal Operation; Donors: 2 air, 1 Ground Sta.	13.11	3.09

3.6.3 <u>Oscilloscope Photographs of the Signals</u>

This section contains photographs of the epoch-start triads and fine-synchronization triads as received by the MICRO CAS equipments during the synchronization support testing. The raw video outputs of the MICRO CAS receivers were recorded on video tape for this later study of what constituted acceptable and unacceptable signals and to examine the effect of simultaneously arriving multiple signals. The video tape was played back, and the output was displayed on the oscilloscope for photography. The "pause" mode of playback permitted leisurely study and photographing of the received signals.

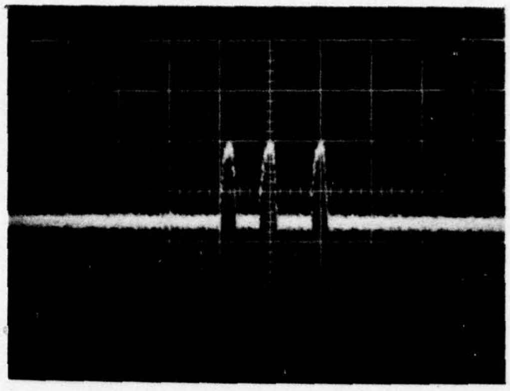
Figure 3.22 shows, on the left, three examples of merged epoch-start triads that were accepted and, on the right, three examples of merged epoch-start triads that were rejected. Photograph A is an example of a perfectly merged set of epoch-start triads. Photograph B is a merged set that barely passed the acceptance test. Photograph C has two triads fully merged, while the third triad is much weaker and is partially merged. If the third triad had been much stronger, its second pulse would have widened the third pulse in the photograph and the triad would have been rejected. The widening is perceptible at the base of the pulse in the photograph. Photograph D shows perfectly merged triads, but phase differences caused fading that severely notched the peaks of the pulses. Photographs E and F are merged triads with pulses that are, respectively, barely too wide and distinctly too wide.

Figure 3.23 shows two examples of accepted epoch-start triads and four examples of interleaved epoch-start triads that were rejected. In Photograph A one triad is quite clear of the other two, which are interleaved. The nearer aircraft is seven miles (43 microseconds) closer than the other two aircraft. In Photograph B the clear triad is just comfortably clear. If the range difference between the two nearest aircraft had been 3 1/2 miles instead of four miles, the triad would have been rejected. Photograph C shows the triads as they are merging. The range difference between the nearest and farthest aircraft is just over one mile. Photograph D is unusual in that it shows the pulses all to be the same strength. Photograph E shows three distinctly different signal strengths. Photograph F is also unusual in that it shows the three triads fully interleaved, but with all nine pulses distinct. Sophisticated techniques could properly decode epoch start from such configurations. Fortunately, such heroic measures are not required.

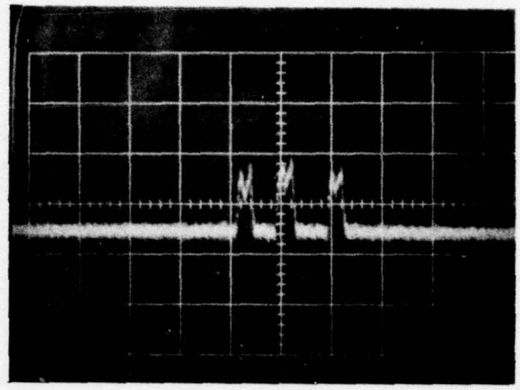
Figure 3.24 consists of photographs of fine-synchronization triads. Photographs A and B are typical of triads that were accepted. Photograph C shows pulses that were distorted by phase differences in the signals received from the different sources. This triad was rejected. While some triads must have been rejected because the pulses were too wide, the resolution of the recording and playback technique was not fine enough to display these differences of tenths of microseconds. The rejected triads for which the cause of rejection was visible were all distorted similarly to the example shown.

3.7 MULTIPLE-AIRCRAFT TESTS

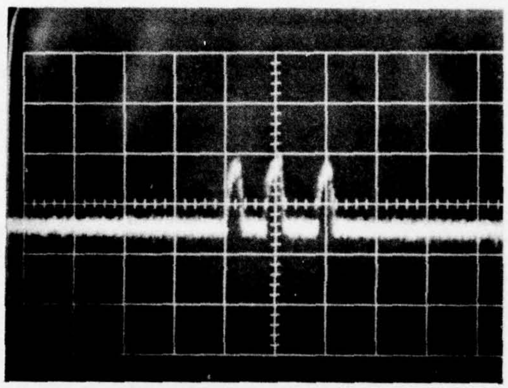
The multiple-aircraft tests involved 5 airborne CAS equipments and a ground station that operated as both a T/F CAS ground station and as a signal simulator to provide RF energy in the various time slots. By radiating RF energy in the time slots, the simulator would make these slots invalid for use by properly operating CAS equipments.



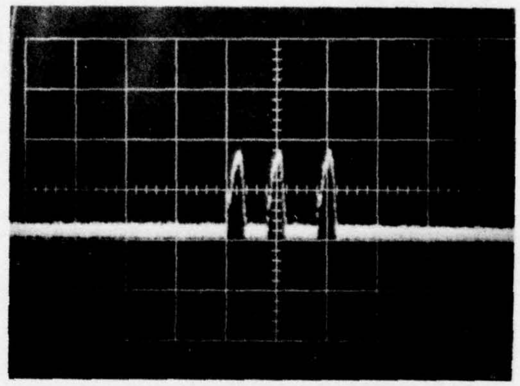
A. Accepted



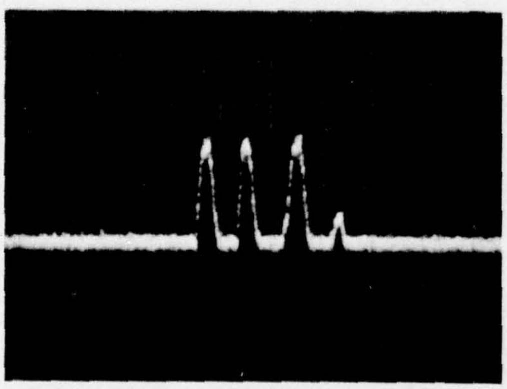
D. Rejected



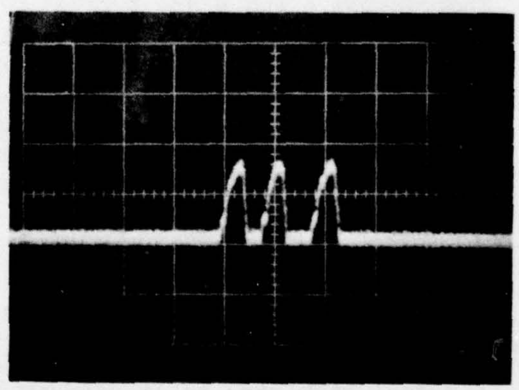
B. Accepted



Rejected



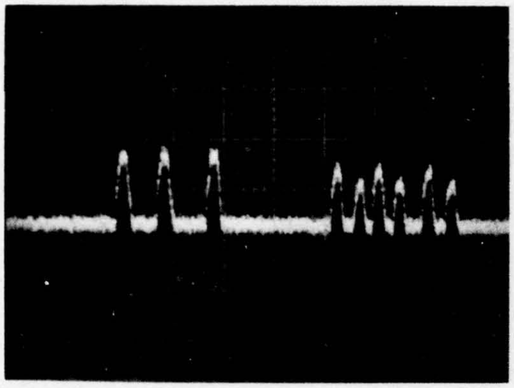
C. Accepted



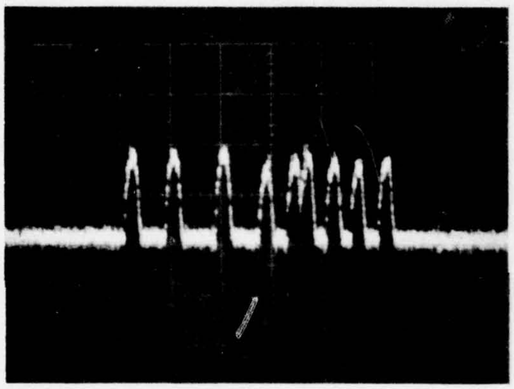
F. Rejected

All Photographs 10 μsec/Division

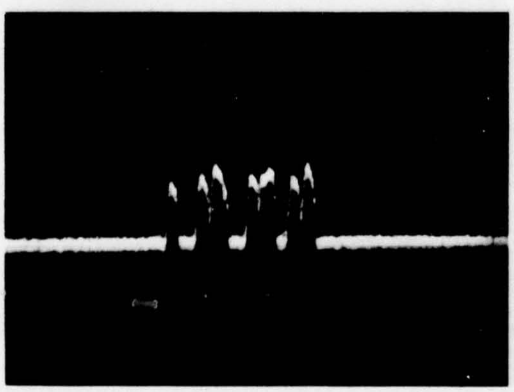
Figure 3-22. SCOPE PHOTOGRAPHS OF MERGED EPOCH-START TRIADS



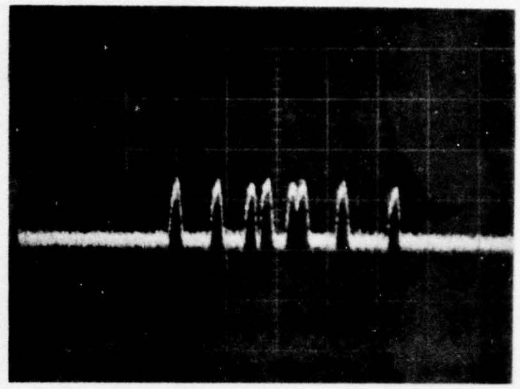
A. Accepted



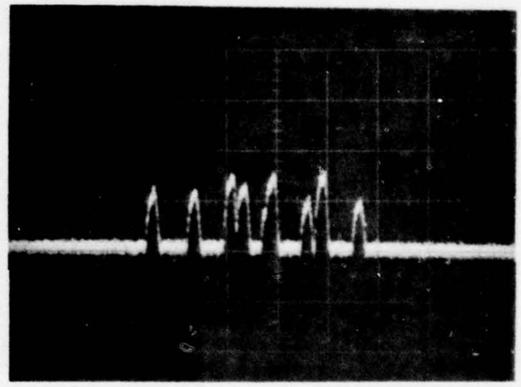
B. Accepted



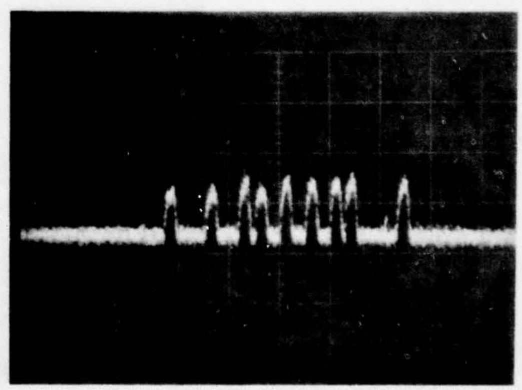
C. Rejected



D. Rejected



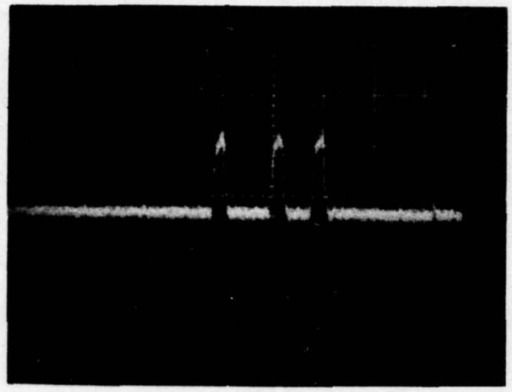
E. Rejected



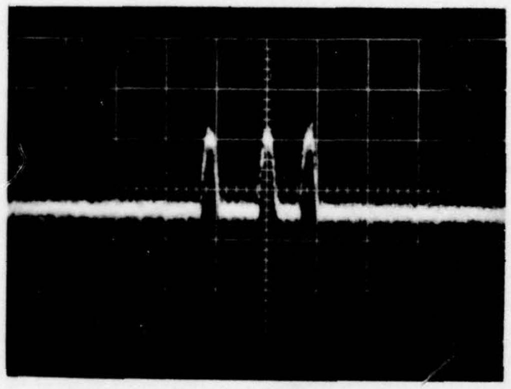
F. Rejected

All Photographs 10 μsec/Division

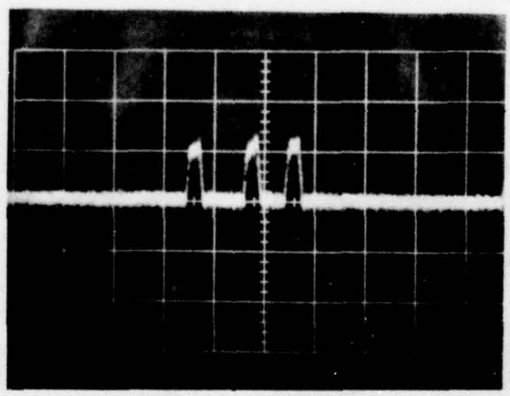
Figure 3-23. SCOPE PHOTOGRAPHS OF INTERLEAVED EPOCH-START TRIADS



A. Accepted



B. Accepted



C. Rejected

All Photographs 10 μsec/Division

Figure 3-24. SCOPE PHOTOGRAPHS OF FINE-SYNCHRONIZATION TRIADS

The traffic simulator is described in Appendix G. It should be noticed that the simulator provides a large amount of control over the time slots that it can jam. However, it is also important to realize that the peak power being transmitted would drop sharply as a large percentage of the time slots were being jammed.

During the multiple-aircraft test, the simulator was operated so as to continuously jam the slots that the CAS equipments were occupying and force them to move to new time slots. Figures 3-25 and 3-26 show two cases in which the simulator jammed 1000 of the 2000 time slots and the resulting slot changes taken by the various CAS equipments. In every case but one the CAS units quickly identified the fact that they were being jammed in their time slot and moved to a new time slot. In the case of the FULL CAS equipments, the future time slots were also changed as a result of the jamming. In Figure 3-25 the FULL CAS on C131 #819 was very late in detecting the simulated co-slot occupant. The reason for this delay in detection is that the aircraft tested for co-occupants with the lower antenna. The aircraft was in a bank with that antenna tilted away from the ground station; hence it was unable to hear the ground station or the jamming signal and was unable to move to a new slot. However, the future slot was modified much earlier because the FULL CAS was continually identifying what it believed to be a valid future slot.

Figure 3-27 shows the resulting slot changes when only 12 slots were made available to four CAS units. The delay in changing time slots by the equipments on C131 #819 is due to the fact that the signal simulator was radiating at very low power when all but 12 slots were being filled. As a result, the equipments on this aircraft could not detect the jamming signals until C131 #819 was within 5 miles of the signal simulator.

The multiple-aircraft tests indicated that the CAS equipments will change their time slot when a co-slot occupant is detected. However, the practical problem with the power radiated by the signal simulator made the flight-test results somewhat inconclusive. The problem of multiple aircraft trying for a limited number of time slots was better studied in the laboratory.

3.8 THREE AIRCRAFT ENCOUNTERS

The EROS II, Model 2002, MICRO CAS does not measure the rate of closure of intruding aircraft; therefore, the protection envelope for the MICRO CAS has boundaries in the horizontal plane that are defined by only the range to the intruding aircraft. The values incorporated in the equipments tested were 2.25 nautical miles for the Tau 2 boundary and 1.5 nautical miles for the Tau 1 boundary. The fixed boundaries for the protection envelope make the timing of the detection of a threat dependent on the rate of closure, with detection occurring earlier than is desirable at low closing rates and later than is tolerable at high closing rates.

Aircraft	System	Slot Type	Active/Future Slots by Epochs																					
			297	298	299	300	301	302	303	304	305	306	307	308	309	310	311	312	313	314	315	. . .	347	348	349	350
C-131 #819	Full	Active	4																			. . .		169		
		Future	165											169								. . .		12		
	Micro	Active	21				25															. . .				
C-131 #804	Full	Active	9																8			. . .				
		Future	23																14			. . .				
	Micro	Active	10											18								. . .				
KC-135	Full	Active	172						2													. . .				
		Future	1630						13													. . .				

At epoch 298 the traffic simulator (in switch position 2):

Denied slots 3,4,5, 9,10,11, 15,16,17, 21,22,23, . . .

Made available slots 0,1,2, 6,7,8, 12,13,14, 18,19,20, . . .

Figure 3-25. SLOT CHANGES WITH HALF THE SLOTS AVAILABLE

Aircraft	System	Slot Type	Active/Future Slots by Epochs																									
			367	368	369	370	371	372	373	374	375	376	377	378	379	380	381	382	383	384	385	386	387	388	389	390	391	392
C-131 #819	Full	Active	169				16																					
		Future	12				171																					
	Micro	Active	25							33																		
C-131 #804	Full	Active	8										21															
		Future	14										27															
	Micro	Active	18																							34		
KC-135 #125	Full	Active	2																22									
		Future	13																4									

At epoch 368 the traffic simulator (in switch position 1):

Denied slots 0,1,2, 6,7,8, 12,13,14, 18,19,20, . . .

Made available slots 3,4,5, 9,10,11, 15,16,17, 21,22,23, . . .

Figure 3-26. SLOT CHANGES WITH SIMULATOR CHANGED FROM SWITCH POSITION 2 TO SWITCH POSITION 1

Aircraft	System	Slot Type	Active/Future Slots by Epochs																							
			2543	2544	2545	2546	2547	2548	2549	2550	. . .	2616	2617	2618	2619	2620	2621	2622	2623	. . .	2630	2631	2632	2633	2634	2635	2636
C-131 #819	Full	Active	3								. . .									. . .			543	545			
		Future	23								. . .									. . .			545	7			
	Micro	Active	21								. . .				477	541				. . .							
C-131 #804	Full	Active	157			544					. . .									. . .							
		Future	159			733					. . .									. . .							
	Micro	Active	162			542					. . .									. . .							

At epoch 2544 the traffic simulator was set so the only valid slots were 540-545 and 732-737.

Figure 3-27. SLOT CHANGES WITH ONLY 12 SLOTS AVAILABLE

It should be pointed out that McDonnell Douglas has recommended that the MICRO CAS only be installed in general-aviation aircraft. However, because some of these aircraft can operate at speeds of 150-200 knots and turbine aircraft are allowed to operate at 250 knots below 10,000 feet, it was believed that the 400-knot closing rates used during this test were realistic.

In an encounter at high closing rate between a FULL CAS and a MICRO CAS, the late detection by the MICRO CAS is of no real consequence because the FULL CAS will detect the threat in time to permit a safe altitude separation to be attained through maneuver by the FULL CAS-equipped aircraft alone. In such an encounter the safe separation will be attained before the Tau 1 boundary range of the MICRO CAS is reached; thus all escape maneuvers are executed by the FULL-CAS equipped aircraft. However, if a third aircraft is involved in the situation, the properly timed detection of the threat by the FULL CAS is of no avail if the maneuvers of the FULL CAS-equipped aircraft are constrained by the presence of the third aircraft. The three-aircraft encounters in the flight-test program were designed to obtain data on the system responses in such situations

Three basic encounter configurations were used in the three-aircraft encounters. In all of the configurations, the aircraft at the middle altitude was operating a FULL CAS and the aircraft at the low altitude was approaching head-on while operating a MICRO CAS. In the first configuration the third aircraft was nearly directly above the middle aircraft and was operating a FULL CAS. In the second configuration the third aircraft was again nearly directly above the middle aircraft but was operating a MICRO CAS. In the third configuration the third aircraft was operating a MICRO CAS and was flying as the high aircraft almost directly above the low aircraft so that the middle aircraft, operating a FULL CAS, had to fly between two MICRO CAS-equipped aircraft.

An encounter in the first configuration is diagrammed in Figure 3-28. The vertical line represents the epoch in which the flight paths of middle aircraft and the low aircraft crossed. Prior to that epoch the aircraft were approaching each other, and subsequent to that epoch they were leaving each other. The horizontal lines show the epochs in which the aircraft generated threat indications. The annotations on the lines show the particular threat indication that was generated. The high aircraft is shown to have displayed, except for one epoch, a continuous limit-dive indication that would prevent the pilot from descending into the middle aircraft. Except for a few epochs in which received transmissions were rejected, the middle aircraft displayed the complementary limit-climb command. The presence of the high aircraft placed a strong constraint on vertical maneuvers by the middle aircraft. The CAS would permit raising the altitude by 200 feet to 8,600 feet but attempts to go higher would result in dive commands to re-establish an altitude separation of at least 600 feet. The figure shows that the middle aircraft detected the threat of the low aircraft 13 epochs (39 seconds) prior to a possible "collision". At that time the positions of the air-

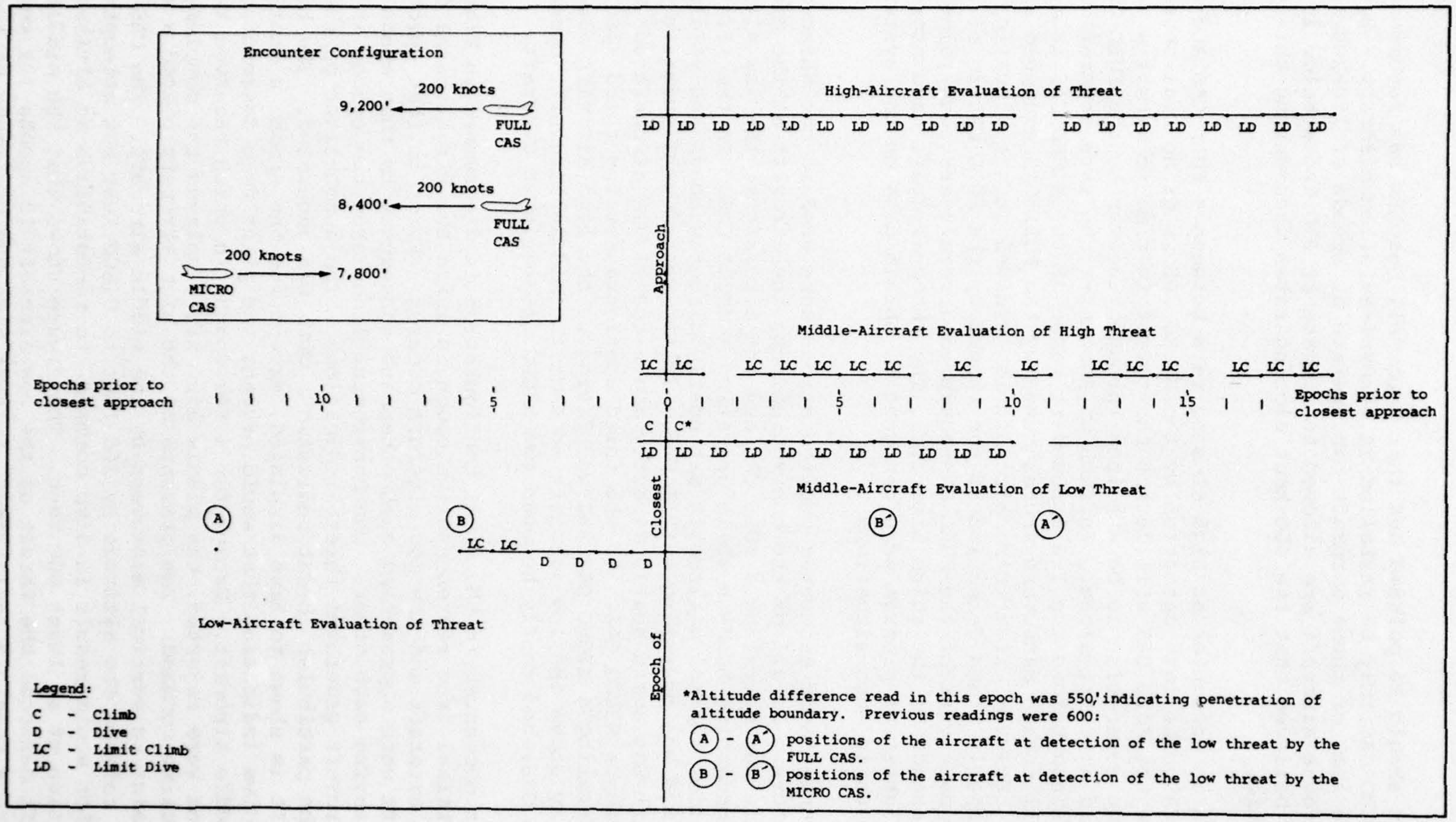


Figure 3-28. THREE-AIRCRAFT ENCOUNTER IN CONFIGURATION ONE

craft were as shown by A and A' in the diagram. The MICRO CAS did not detect the threat until six epochs (18 seconds) prior to a possible collision. At that time the positions of the aircraft were as shown by B and B'. During the time lapse (21 seconds) between points A and B the middle aircraft was constrained from maneuvering and the threatening aircraft was unaware of the developing hazardous situation. It was not until four epochs (12 seconds) remained that the MICRO CAS generated the dive command that would clear the situation. In this encounter the threatened aircraft were exactly on the altitude boundary of the maneuver command zone. Apparently the MICRO CAS included the boundary in the threat zone because it generated dive commands, and apparently the full CAS did not include the boundary in the threat zone because it did not generate a climb command until it read an altitude difference of 550 feet in the last epoch before cross-over, as noted on the diagram.

An encounter in the second configuration is shown in Figure 3-29. The high aircraft was actually flying at 9,200 feet but was decoding its altitude as 8,800 feet because of an intermittently faulty flip-flop in the altitude decoding circuitry that, when malfunctioning, caused reversed decoding of the C1 and C4 bits of the coded altitude from the altimeter. This created an anomalous situation in that maneuver commands were being ignored, but it did not interfere with the desired objective of the test. Just as in the first case, the high and middle aircraft generated complementary indications. The full system in the middle aircraft detected the threat from the low aircraft with 17 epochs (51 seconds) to go. The MICRO CAS in the low aircraft detected the threat with six epochs (18 seconds) to go and generated the dive command to clear the situation with four epochs (12 seconds) to go. The aircraft were again exactly on the altitude boundary of the maneuver zone, and the FULL CAS did not develop a maneuver command except during two epochs in which the altitude separation from the low aircraft was read to be 550 feet. Since there was an above intruder already in the maneuver zone, the middle-aircraft CAS generated a level-off command upon detecting a below intruder in the maneuver zone. In this encounter the period in which the maneuvers of the middle aircraft were restricted and the threatening aircraft was unaware of the threat was 33 seconds. Another six seconds then elapsed before the threatening aircraft would have started an escape maneuver.

An encounter situation of the third configuration is diagrammed in Figure 3-30. In this encounter the middle aircraft was to pass between the two MICRO CAS-equipped aircraft. The threatening aircraft was the high one, with 400 feet separation, and the constraining aircraft was the low one, with 700 feet separation. As the encounter was actually flown, the high aircraft was nine seconds behind the low aircraft; therefore, the line representing the epoch of closest approach for the high threat has been offset by three epochs to keep the two threats time-correlated.

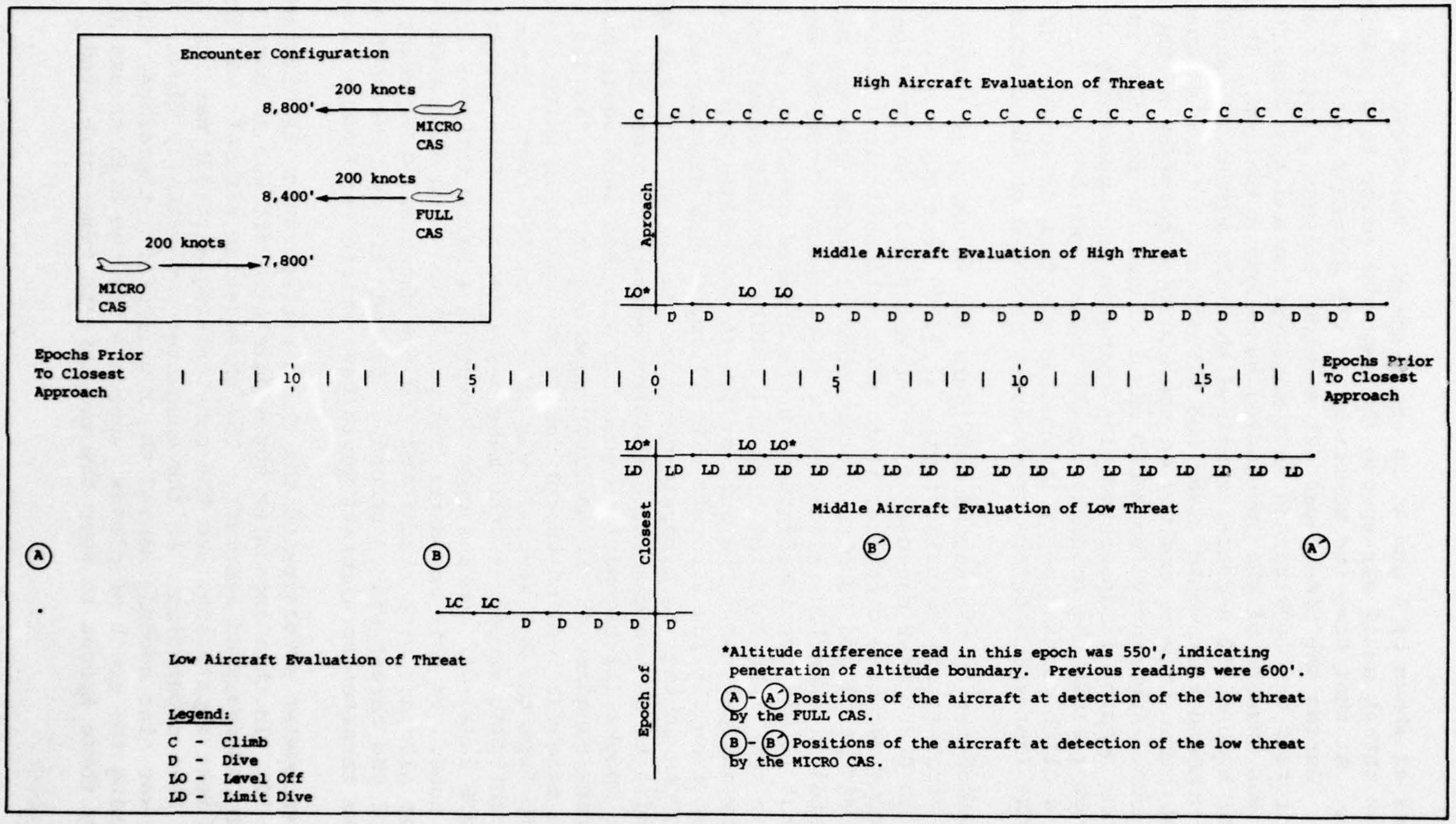


Figure 3-29. THREE-AIRCRAFT ENCOUNTER IN CONFIGURATION TWO

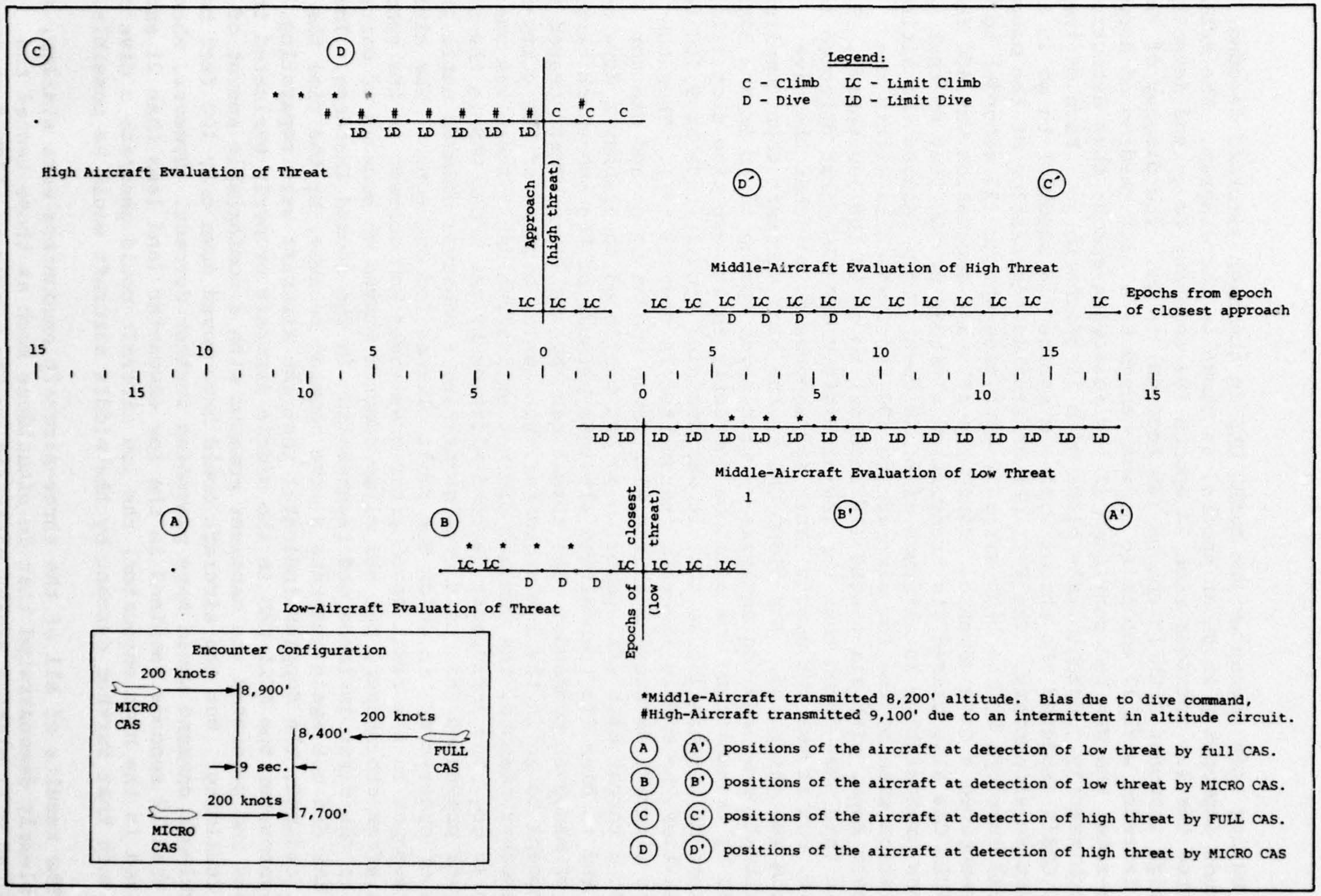


Figure 3-30. THREE-AIRCRAFT ENCOUNTER IN CONFIGURATION THREE

During this encounter the MICRO CAS in the high aircraft decoded altitude improperly in seven epochs, as shown in the diagram. The FULL CAS detected the low intruder with 14 epochs (42 seconds) to go and detected the high intruder with 15 epochs (45 seconds) to go. The display of the high intruder with 17 epochs to go was caused by a high reading of doppler range-rate, and was not confirmed in the following epoch; thus detection was arbitrarily judged to take place with 15 epochs to go. Each of the MICRO CAS's detected the threat with six epochs (18 seconds) to go in their respective encounters. The FULL CAS determined penetration of the maneuver-command envelope by the high aircraft with nine epochs (27 seconds) to go and generated a dive command. Since the altitude separation was 400 feet, the FULL CAS also biased its transmitted altitude by 200 feet so that it was now transmitting an altitude of 8,200 feet. This reduced the altitude separation seen by the low aircraft to 500 feet, which is within the maneuver zone, with six epochs (18 seconds) to go in the low threat. It was in this same epoch that the low-aircraft MICRO CAS first detected the threat, but it was two epochs later (12 seconds to go) that the dive command was generated. The MICRO CAS in the high aircraft then complicated the situation -- and the analysis -- with seven epochs to go in the high threat by transmitting its altitude correctly in its own time slot (slot 2) and then malfunctioning so that it was decoding its altitude as 9,100 feet by the time the middle aircraft transmitted in time slot 61. Thus the middle aircraft detected a threat with seven epochs to go and did not detect a threat with six epochs to go but continued to display a dive command and to bias its transmitted altitude because of the one-epoch carry-over of maneuver commands. The threat seen by the low aircraft ceased with two epochs to go in the low encounter, but again, because of the carry-over of maneuver command, the command did not extinguish until there was one epoch to go. The improperly decoded altitude by the MICRO CAS in the high aircraft prevented that unit from generating a maneuver command until the epoch of cross-over, in which the fault cleared for one epoch. The altitude was improper in the first epoch after cross-over and correct in the second epoch after cross-over, but the climb command stayed on because of carry-over in the first instance and regeneration in the second instance. The FULL CAS did not again generate a dive command because, by the time the fault cleared, the doppler indicated that the aircraft were separating. this encounter the FULL CAS in the middle aircraft properly evaluated the threats and generated the maneuver command with a comfortable amount of time remaining. But the aircraft could have moved down only 100 feet before a level-off command would have prevented further descent. However, when less than 12 seconds remained in the low encounter (and less than 21 seconds remained in the high encounter) the low aircraft could generate a dive command such that further descent by the middle aircraft would be possible.

The results of all of the three-aircraft encounters were similar, and they clearly demonstrated that in situations such as those tested the MICRO CAS will place a severe restraint on the maneuvers allowed an opposing FULL CAS until the time remaining for escape is hazardously short.

These fixed boundaries for the protection envelope, as mentioned earlier, cause the warning times to be dependent on the rate of closure between the aircraft. The boundaries selected, 2.25 n.mi. and 1.5 n.mi. for Tau 2 and Tau 1, respectively, provide 40-second warning time and 25-second maneuver time at a closing rate of approximately 205 knots. As the closing rate increases, the times decrease until at the 500-knot maximum closing that can occur below 10,000 feet (250-knot speed restriction) the times are 16 seconds for warning and only 11 seconds for maneuver. Because of the three-second sampling interval, these times could go as low as 13 seconds and 8 seconds, respectively. At the other end of the closing-rate range the times increase to the point where they become grossly excessive. At a 100-knot closing rate the warning time is 81 seconds and the maneuver time is 54 seconds. Thus, where two MICRO CAS-equipped aircraft are involved, at the higher closing rates the safety margin is reduced, while at the low closing rates the system effectiveness may be reduced because false alarms occur so often that the pilots begin to ignore them, or at lease become desensitized to the point of having slow reactions.

It is quite clear that fixed boundaries for the protection envelope may not be satisfactory or acceptable. It also seems quite clear that the doctrine of unilateral escape maneuvering does not always extend to situations involving more than two aircraft. While no CAS responders have been built or tested, the responder concept is definitely unacceptable when viewed in the light of experience with the MICRO CAS.

3.9 SUPERSONIC ENCOUNTERS

The data collected during the supersonic mission were analyzed separately because the quantity of data was limited, the mission profile was different from any of the conventional two-aircraft encounters, and some special problems were encountered during this test that made it necessary to examine the data manually. The supersonic mission consisted of two flights during which the following encounters were obtained:

Flight	Encounter	CAS Mode	Approximate Closing Rate
1	1	Synchronized	1110 kts
1	2	Synchronized	1720 kts
2	3	Back-up mode	1650 kts
2	4	Back-up mode	1680 kts
2	5	Synchronized	1100 kts

The first encounter should have been flown at supersonic speeds (2 x 590 knots at 29,000 feet) but was not because the pilots decided to fly one high subsonic run first to check out visibility and fire-control radar lock-on ranges at a slower closing rate. The fifth encounter was not in the original test plan, but the F106's had enough fuel remaining for a subsonic encounter, and it was decided to fly an additional pass. All five of these encounters are referred to as supersonic encounters although the name is not suited to two of the cases.

During the supersonic missions the reliability of communications between the aircraft was extremely poor. Table 3-6 summarizes the communications reliability as a function of three range bins for the two F106 aircraft. The low communications reliability was mainly attributed to an RF noise source on the F106 aircraft, the Grimes light, or the rotating beacon. Chapter Four discussed interference that was caused by a Grimes light during a laboratory experiment. It would not be surprising if the F106's had an RF noise source capable of causing these problems while the other aircraft did not, because the C131's and the KC135 aircraft were special electronic-test-bed aircraft while the F106 aircraft were operational fighters. The apparent inconsistencies in the communications reliability between encounters involving the same aircraft are most likely due to intermittent emissions by the Grimes light. The data for the F106 aircraft during the synchronization test indicated periods of very high communications reliability and periods of very low communications reliability; and this is consistent with the varying communications reliability observed during the supersonic mission. The quick-look data analysis did reveal that there would be some problems in analyzing the supersonic mission data, but the full impact of the communications reliability problem was not realized at this time. It should be pointed out that the problems associated with the Grimes light were verified only after a period of laboratory testing, and a repetition of the supersonic mission with the Grimes lights still on would have accomplished little.

The epochs during the supersonic mission for which usable data were recorded have been analyzed. Table 3-7 gives the mean and standard deviation for the range, range-rate, and altitude errors for the synchronized encounters and the same statistics for the range rate and altitude during the backup-mode encounters. The range-rate errors for the synchronized encounters generally agree with the results derived during the subsonic two-aircraft encounters. It will be recalled that the McDonnell Douglas photo panel instrumentation was verified to indicate ranges with an average error of 0.05 n.mi. However, the range-rate errors are larger in absolute value, and the overall standard deviation of the altitude measurements is larger than those in Table 3-4 for the full systems. Although the range-rate errors are larger in absolute value, their effect on determining the Tau boundary should be reduced because these errors are a smaller percentage of the actual closing rate. The back-up-mode data indicate no reduction in the ability of a FULL CAS to measure range rate and altitude when operating in back-up mode at supersonic closing rates. Therefore, the system is theoretically capable of providing adequate protection in back-up mode at supersonic speeds.

Table 3-6. SUPERSONIC-MISSION COMMUNICATIONS RELIABILITY

Data Source	Range Bins		
	0-15 n.mi.	15-45 n.mi.	45-75 n.mi.
Encounter 1: F-106 #075	1.000	0.176	0.000
Encounter 1: F-106 #069	0.941	0.618	0.676
Encounter 2: F-106 #075	0.200	0.136	0.000
Encounter 2: F-106 #069	0.800	0.240	0.522
Encounter 5: F-106 #075	0.235	0.438	0.000
Encounter 5: F-106 #069	0.235	0.594	0.000
All Synchronized Encounters			
Encounter 3: F-106 #075	0.400	0.150	0.000
Encounter 3: F-106 #069	0.400	0.318	0.167
Encounter 4: F-106 #075	0.818	0.050	
Encounter 4: F-106 #069	0.818	0.250	
All Back-Up Mode Encounters	0.619	0.195	0.080

Table 3-7. SUPERSONIC-MISSION STATISTICS

Data Source	Range Errors (n.mi.)		Range-Rate Errors (Knots)		Altitude Errors (Feet)	
	Mean	Standard Deviation	Mean	Standard Deviation	Mean	Standard Deviation
Encounter 1: F-106 #075	.0964	.0604	31.5	60.9	-31.8	71.6
Encounter 1: F-106 #069	.0712	.0601	--	--	53.7	143.4
Encounter 2: F-106 #075	.1080	.0709	18.6	76.4	-60.0	54.8
Encounter 2: F-106 #069	.0985	.0754	118.8	104.0	25.9	71.2
Encounter 5: F-106 #075	.0839	.0509	29.7	75.7	-50.0	51.5
Encounter 5: F-106 #069	.0522	.0483	58.5	40.5	47.8	89.8
Synchronized Encounters: F-106 #075	.0927	.0565	29.3	66.5	-42.2	61.4
Synchronized Encounters: F-106 #069	.0745	.0639	91.1	85.1	44.0	112.1
All Synchronized Encounters	.0805	.0621	61.8	82.8	15.4	106.3
Encounter 3: F-106 #075	--	--	24.0	63.0	-114.0	107.0
Encounter 3: F-106 #069	--	--	145.8	114.8	11.0	93.0
Encounter 4: F-106 #075	--	--	-7.0	37.0	-20.0	42.0
Encounter 4: F-106 #069	--	--	107.0	49.0	50.0	76.0
Back-Up Mode Encounters: F-106 #075	--	--	6.0	49.0	-59.0	60.0
Back-Up Mode Encounters: F-106 #069	--	--	123.0	81.0	35.0	81.0
All Back-Up Mode Encounters	--	--	74.4	90.5	-5.0	86.5

To provide an additional illustration of the performance of the CAS at supersonic speeds, Figures 3-31 and 3-32 show the radar and the CAS range and range rates during two encounters where there was a relatively high percentage of CAS data. The corresponding CAS and radar data points occur at essentially identical ranges, but the range-rate error can be quite large. Figure 3-32 illustrates the effect that data dropouts can have on the generation of an alarm.

3.10 BACK-UP-MODE TEST

Back-up mode is an alternate mode of operation of the T/F CAS in which the equipments operate asynchronously because they do not have a common time base. The back-up-mode capability was provided to permit the collision-avoidance function to continue into areas which are remote from ground stations and in which the air-traffic density is too low to provide an unbroken propagation chain back to a ground station. Because the frequencies of the reference oscillators are less precise in the absence of fine-synchronization support, the protection envelope, when operating in back-up mode, is designed to provide both maneuvers and warnings with 40 seconds or more time to go before the point of closest approach. Since back-up mode is an alternate mode, it received less attention than the synchronized mode, the objective of the testing being to develop statistics on the accuracy of measurement of range rate and the time of generation of the replies and to obtain data on the specific instructions contained in the replies.

3.10.1 <u>Accuracy of Range-Rate Measurement and Reply Generation</u>

The back-up mode tests were conducted following the three-aircraft encounters. Therefore, the CAS equipments had been operating for more than two hours with continuous fine-synchronization support, and the oscillators were fully settled in frequency. Fine-synchronization support was terminated, and the systems were allowed to demote into back-up mode. Coarse-synchronization support was continued to keep the epoch counts by the instrumentations aligned so that the problem with epoch-count alignment encountered in the supersonic back-up-mode tests could be avoided.

FULL CAS serial number 1 was installed in the high aircraft, KC-135 (125), and FULL CAS serial number 2 was installed in the low aircraft, C-131 (819). The mean values and standard deviations of the errors in range-rate measurement and in time of generation of the back-up-mode warning reply for each system are shown in Table 3-8. In back-up mode, an aircraft should transmit a warning pulse at 2951-T microseconds, where T is the larger of $T = 2(40\dot{R} + 1.8)/C$ and $T = 1/C$ (C = speed of light in n.mi./μsec). The warning-time errors are the difference between the calculated time and the actual time as recorded by the ATA instrumentation.

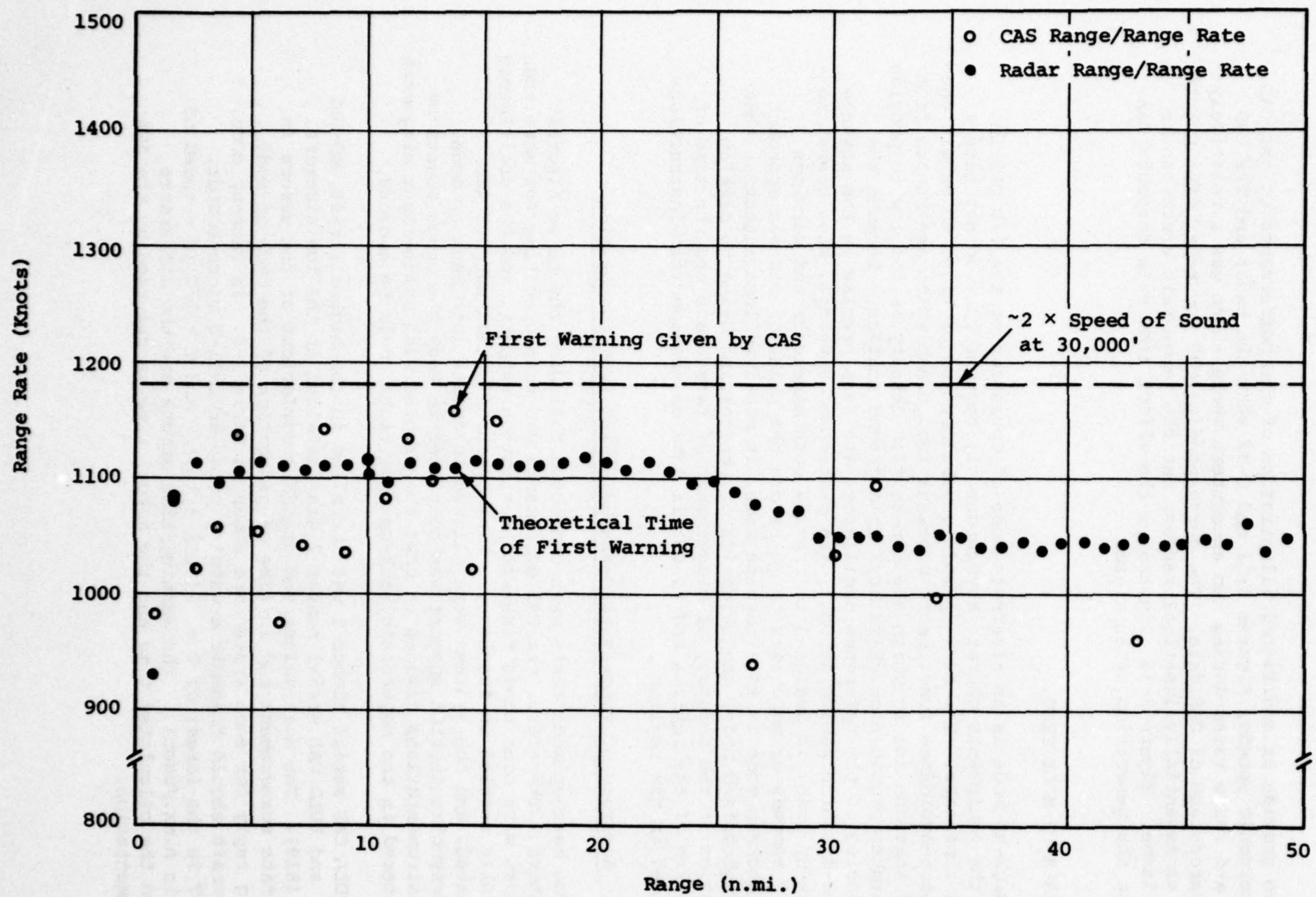


Figure 3-31. SUPERSONIC ENCOUNTER 1 FOR F-106 #075

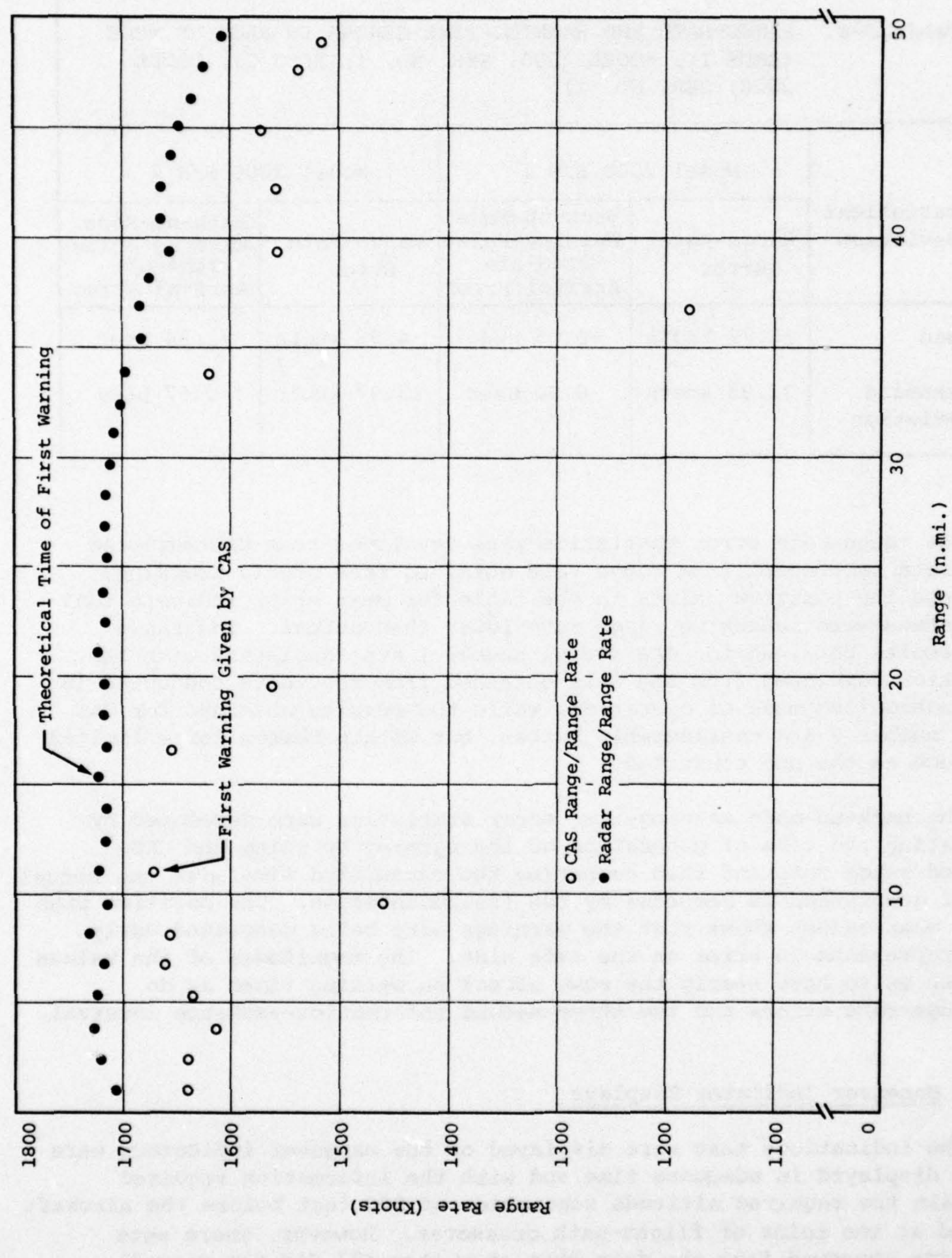


Figure 3-32. SUPERSONIC ENCOUNTER 2 FOR F-106 #069

Table 3-8. RANGE-RATE AND WARNING-TIME ERRORS IN BACK-UP MODE (EROS II, MODEL 2000, SER. NO. 1; EROS II, MODEL 2000, SER. NO. 2)				
Statistical Deviation	Model 2000 S/N 1		Model 2000 S/N 2	
	Range-Rate Error	Back-up-Mode Warning-Pulse Time-of-Arrival Error	Range-Rate Error	Back-up-Mode Warning-Pulse Time-of-Arrival Error
Mean	38.79 knots	+0.05 μsec	4.98 knots	+1.34 μsec
Standard Deviation	31.93 knots	0.90 μsec	13.97 knots	0.67 μsec

The range-rate error statistics were developed from CAS-measured range rate subtracted from range rate obtained from metric tracking; therefore,the positive values in the table for mean error indicate that the systems were measuring range rate lower than actual. The range rate results obtained for CAS serial number 1 are consistent with the statistics developed from the data obtained from the tests conducted in the synchronized mode of operation, while the results obtained for CAS serial number 2 are considerably better, but within reason for a limited test such as the one conducted.

The back-up-mode warning-time error statistics were developed by calculating the time of generation of the warning by using the CAS-measured range rate and then comparing the calculated time with the actual time of generation as recorded by the instrumentation. The positive sign on the mean values shows that the warnings were being generated early, which represents an error on the safe side. The magnitudes of the values are such as to have nearly the same effect on warning times as do the range-rate errors and the three-second information-exchange interval.

3.10.2 Maneuver Indicator Displays

The indications that were displayed on the maneuver indicators were always displayed in adequate time and with the information required to obtain the required altitude separation of 800 feet before the aircraft arrived at the point of flight-path crossover. However, there were anomalies observed from the data that show that all did not go well. Figure 3-33 shows the specific information displayed in each aircraft in each epoch from the epoch in which the first indication appeared in either aircraft to the epoch in which the flight paths crossed.

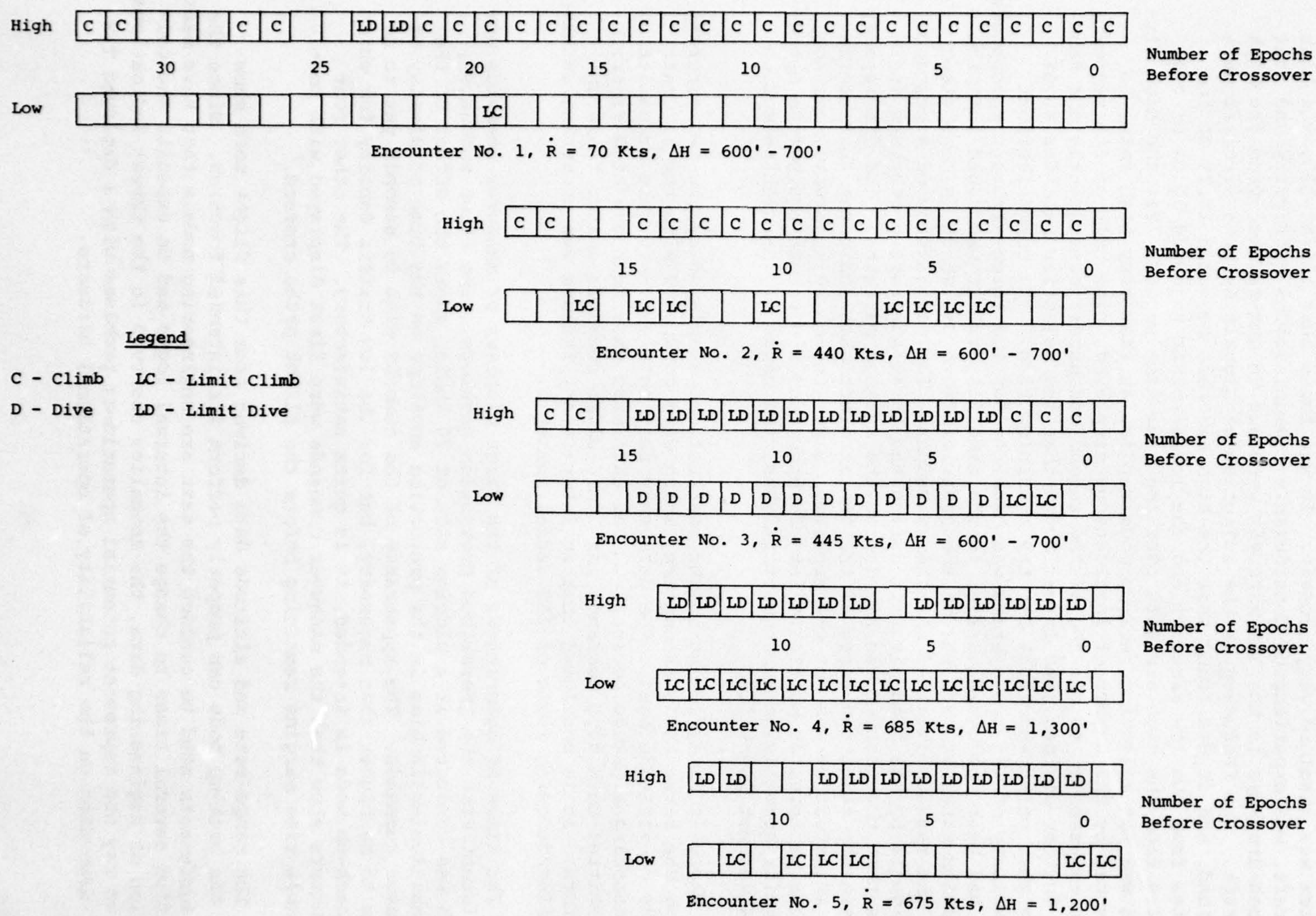


Figure 3-33. MANEUVER INDICATOR DISPLAYS DURING BACK-UP MODE ENCOUNTERS

Because of the large number of non-displays in the low aircraft, that problem was examined very closely. It was found that the KC-135, the high aircraft, was experiencing considerable communications difficulty and that the non-displays in the low aircraft were due to non-replies from the high aircraft. The frequency of the rejection of signals by both aircraft were examined, and it was found that the high aircraft rejected 39.7% of the queries from the low aircraft and the low aircraft rejected 10.0% of the queries from the high aircraft over the same time period. Yet the high aircraft was not rejecting back-up mode replies at that very high rate, as evidenced by the number of instructions displayed. The bulk of the rejections appeared up to the end of the second encounter; consequently the data were further divided, and it was found that the rejection rate was 80.6% up to that point and 23.4% for the remaining time. The communications reliability of the two systems was examined for the three-aircraft encounters that had been conducted earlier in the same flight. It was found that the rejection rates of each was on the order of 2% to 3%, which is consistent with the results obtained on other missions. The consistency of acceptance of signals by the high aircraft during the three-aircraft encounters indicates that the problem was not due to the antenna patterns. The discrepancy between the rejection rates of the two aircraft also indicates that multipath interference was not the problem. Since the cause apparently was not antenna patterns or multipath interference, and since both equipments operated quite normally on subsequent flights, the cause of the high rejection rates was not identified.

There is disagreement in the instructions displayed by the two aircraft during the first three encounters, which were conducted with the aircraft in the co-altitude band. The data show that both aircraft were transmitting and decoding altitude correctly. The data also show that the high aircraft transmitted both dive commands and limit-climb commands during these encounters. It is concluded that an intermittent failure was occurring in the encoding/decoding logic of CAS serial number 1.

The times of occurrences of the first displays of maneuver commands are consistent with the prescribed protection envelope. The first encounter, which was conducted at a closing rate of 70 knots, shows the effect of the 1.8-nautical-mile bias in the protection envelope on the time of display of maneuver commands. The appearance of the command with 99 seconds yet to go seems to be higher than necessary, but for the low traffic density for which the back-up mode is intended, it is quite satisfactory. The other four encounters show that the maneuver commands were first displayed with comfortable time margins remaining before the flight paths crossed.

The range-rate and altitude data derived from this flight test show that the back-up mode can properly perform its intended function. Since the CAS equipments used to conduct the test are engineering models that have been modified several times to change the internal logic and to expedite the collection of engineering data, the anomalies observed in the threat indications may or may not represent potential operational problems with a deployed T/F CAS, depending on the reliability of operational hardware.

3.11 ANALYSIS OF THE McDONNELL DOUGLAS PROPOSED MODIFICATION TO THE RANGE-RATE MEASUREMENTS

McDonnell Douglas is investigating the possibility of a version of T/F CAS that does not measure range rate by measuring the doppler shift in the received range pulse. The new version of T/F CAS would have relaxed demands on the transmitter and permit the MICRO CAS to have full threat logic through the addition of a range capability. The new system would determine range rate by measuring the change in range between successive epochs and dividing this range change by 3 seconds. Single-epoch data dropouts are accommodated by using the range change over two epochs and dividing by 6 seconds. Accommodation of data dropouts in two or more successive epochs is not contemplated. The system design would incorporate a range-rate tracker for each of the 2000 time slots.

A dropout of data in a single epoch would cause only range-rate data for that epoch to be lost. Data dropouts in two successive epochs would cause range-rate data to be lost for three epochs (the two epochs with dropouts and one more epoch to reload the slot tracking memory).

A portion of the range data collected during the T/F CAS test program was analyzed to obtain an indication of how well this new range-rate measurement technique would work. The range rates that would have been generated by a FULL CAS listening to a FULL CAS were calculated and were compared with the doppler range rate that the full system actually measured. The analysis was also made for a FULL CAS listening to a MICRO CAS. The results are as follows:

RANGE RATE DATA: FULL CAS TO FULL CAS

Parameter	Delta Range/Time	Doppler
Mean Range Rate Error	-1.7	-30.1
Standard Deviation	34.5	27.6
Root Means Square (RMS) Error	34.6	40.8

RANGE RATE DATA: MICRO CAS TO FULL CAS

Parameter	Delta Range/Time	Doppler
Mean Range Rate Error	-1.5	-35.5
Standard Deviation	43.9	34.7
Root Mean Square (RMS) Error	43.9	49.6

It is clear that there is virtually no bias in the "delta range" method of determining the range rate. However, it appears that the overall (RMS) errors are approximately equal. The data in the preceding tables are taken from 30, 100, 200, and 400 knots closing-rate encounters; thus, the results in the tables should represent the typical performance of both methods of measuring range rate over the set of closing rates commonly encountered.

CHAPTER FOUR

LABORATORY TESTING OF T/F CAS EQUIPMENT

4.1 GENERAL

Following completion of the flight testing of the T/F CAS, the equipments were moved to ARINC Research Corporation's test laboratory for further testing to obtain additional data that could not reasonably be obtained during the flight phase of the program. Only the first four items listed below were originally planned, as reflected in the CAS test plan. The remaining items were added to the laboratory testing as a result of conditions and events identified during the flight testing.

The laboratory testing activities consisted of the following:

1. Testing of sensitivity to interference from radar altimeters
2. Evaluation of interference effects of helicopter rotor blades
3. Determination of time-slot selection patterns and behavior in a heavy traffic environment
4. Measurement of event pulse time delays from the CAS to the ATA instrumentation
5. Measurement of oscillator-frequency stability and frequency-synchronization accuracy
6. Verification of malfunctions observed during the flight tests
7. Investigation of the operating anomalies observed during the supersonic tests conducted in the CAS back-up mode
8. Measurement of T/F CAS spectra

While the equipments were set up in the laboratory, additional testing was conducted by the Institute of Telecommunications Services (ITS). The purpose of these tests was to evaluate mutual interference effects between T/F CAS and other equipments that operate, or will possibly operate, in adjacent frequency bands. These other equipments were AN/APN-159A, AN/APN-155B, AN/APN-133, Bonzer TRN-70 and IFD-GAR radar altimeters, and prospective satellite communications systems using frequency modulation or delta modulation. The results of the additional interference testing are being published separately by ITS.

4.2 GENERAL DESCRIPTION OF THE LABORATORY TESTS

The equipments were set up for the tests by interconnecting the units with coaxial conductors to serve as the required communications links. Fixed and variable attenuators, directional couplers, and resistive loads were used to obtain both the desired and undesired received signal strengths at each of the units. External test equipments were connected to the communications links and to the test units as appropriate to obtain measurements of the desired parameters. The test configuration schematic used to evaluate the interference effects of the AN/APN-159A radar altimeter on the T/F CAS receiver is shown as an example in Figure 4-1. The communication links to the T&E ground station used to provide synchronization support to the CAS 's under test are not shown, because they were not germane to the tests conducted and they would also substantially complicate the schematic.

4.3 SENSITIVITY TO RADAR ALTIMETER INTERFERENCE

It was originally intended to conduct laboratory tests to determine the CAS's sensitivity to interference only from the AN/APN-159A radar altimeter, but the interference experienced during the flight tests from the AN/APN-155B radar altimeter caused this equipment to be added to the laboratory evaluation.

The frequency spectrum of the AN/APN-159A is shown in Figure 4-2 for the high-altitude mode, photograph A, and for the low-altitude mode, photograph B. The horizontal scale is 50 MHz per division, and the center frequency is 1621 MHz. From the photographs, it can be seen that appreciable power is radiated at the T/F CAS frequencies of 1600, 1605, 1610, and 1615 MHz. Photograph C shows the AN/APN-159A signal as received by the MICRO CAS. The bright lines in the photograph are switching transients in the MICRO CAS receiver, and the other lines are the radar altimeter pulses. The frequencies are, left to right, F-4 (1615 MHz), F-1 (1600 MHz), F-2 (1605 MHz), F-3 (1610 MHz), F-4 (1615 MHz), and F-1 (1600 MHz). The effect of these pulses on the T/F CAS operation is a sharply increased rate of rejection of otherwise perfectly acceptable T/F CAS signals. Some erroneous readings were observed when the radar altimeter was operating, but this problem is an instrumentation problem because the measurement is calculated and displayed even though the CAS may subsequently reject the signal.

The AN/APN-155B radar altimeter transmits a frequency-modulated signal with a maximum deviation of about 15 MHz from the center frequency of 1630 MHz. The modulation is an audio frequency that is swept through the low audio frequencies. The spectrum of the AN/APN-155B is shown in Figure 4-3, photograph A. The center frequency is 1630 MHz, and the frequency scale is 20 MHz per division. It can be seen that the spectrum overlaps the T/F CAS F-4 (1615 MHz) frequency but does not extend to F-3 (1610 MHz) or lower in frequency. When the modulation is at its lowest frequency, the radar altimeter signal appears in about every fortieth F-4 time slot, but it can occupy the entire time slot as shown in photograph B. As the modulation frequency increases, the width of signal decreases, but the frequency of

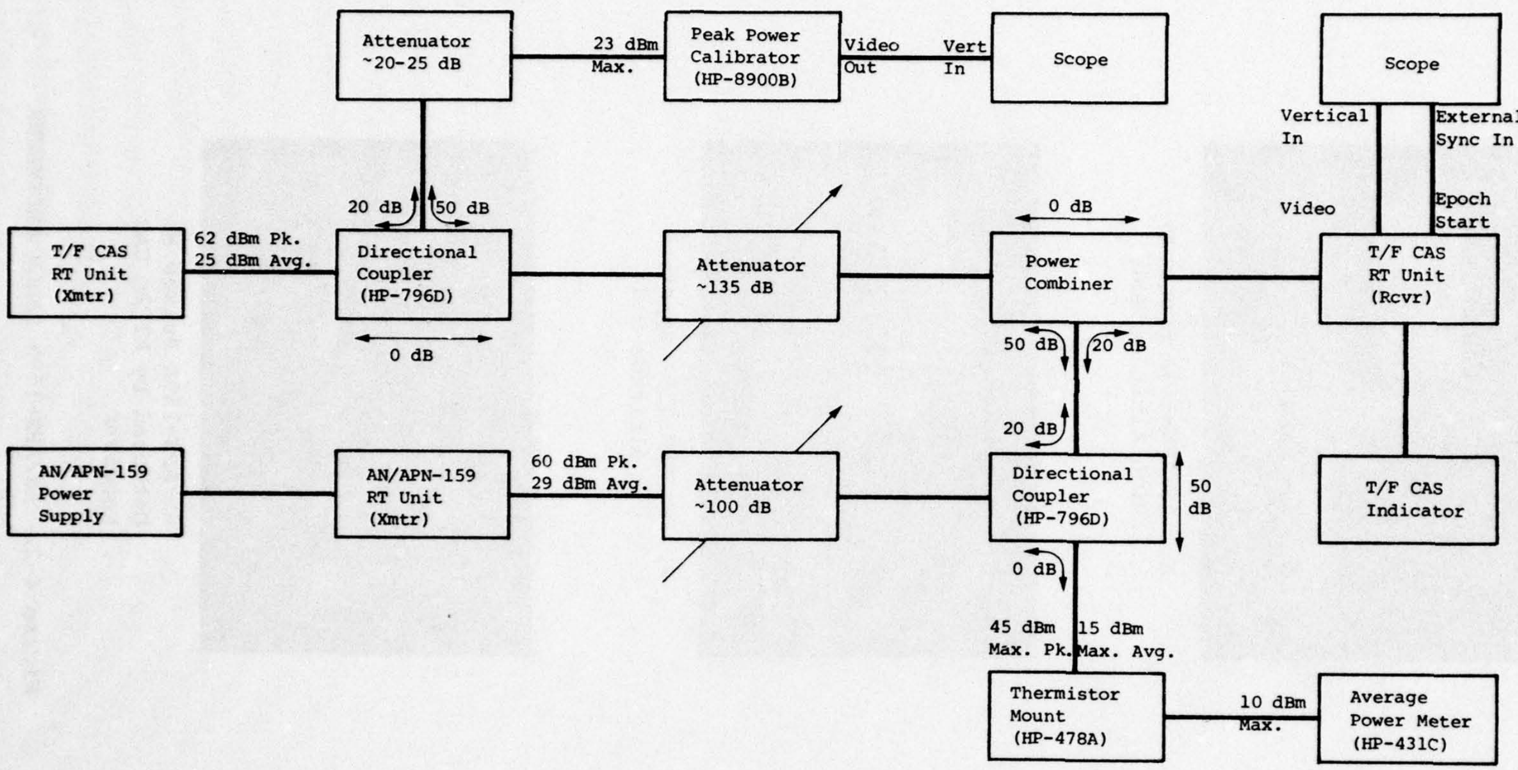
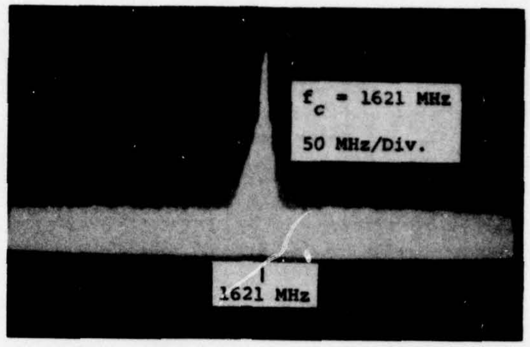
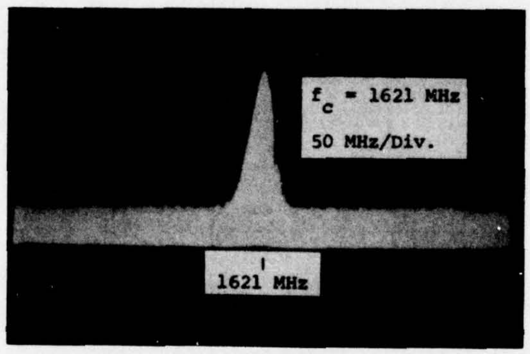


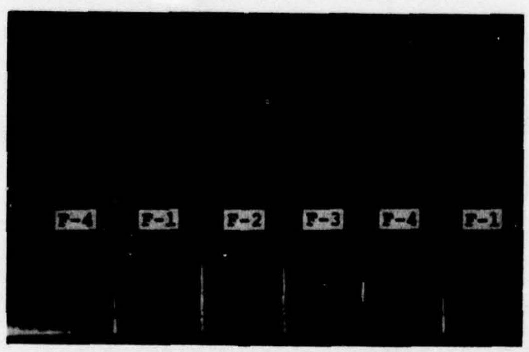
Figure 4-1. TEST CONFIGURATION FOR INTERFERENCE EFFECTS, AN/APN-159 TRANSMITTER TO T/F CAS RECEIVER



A. AN/APN-159A Spectrum
High Altitude Mode

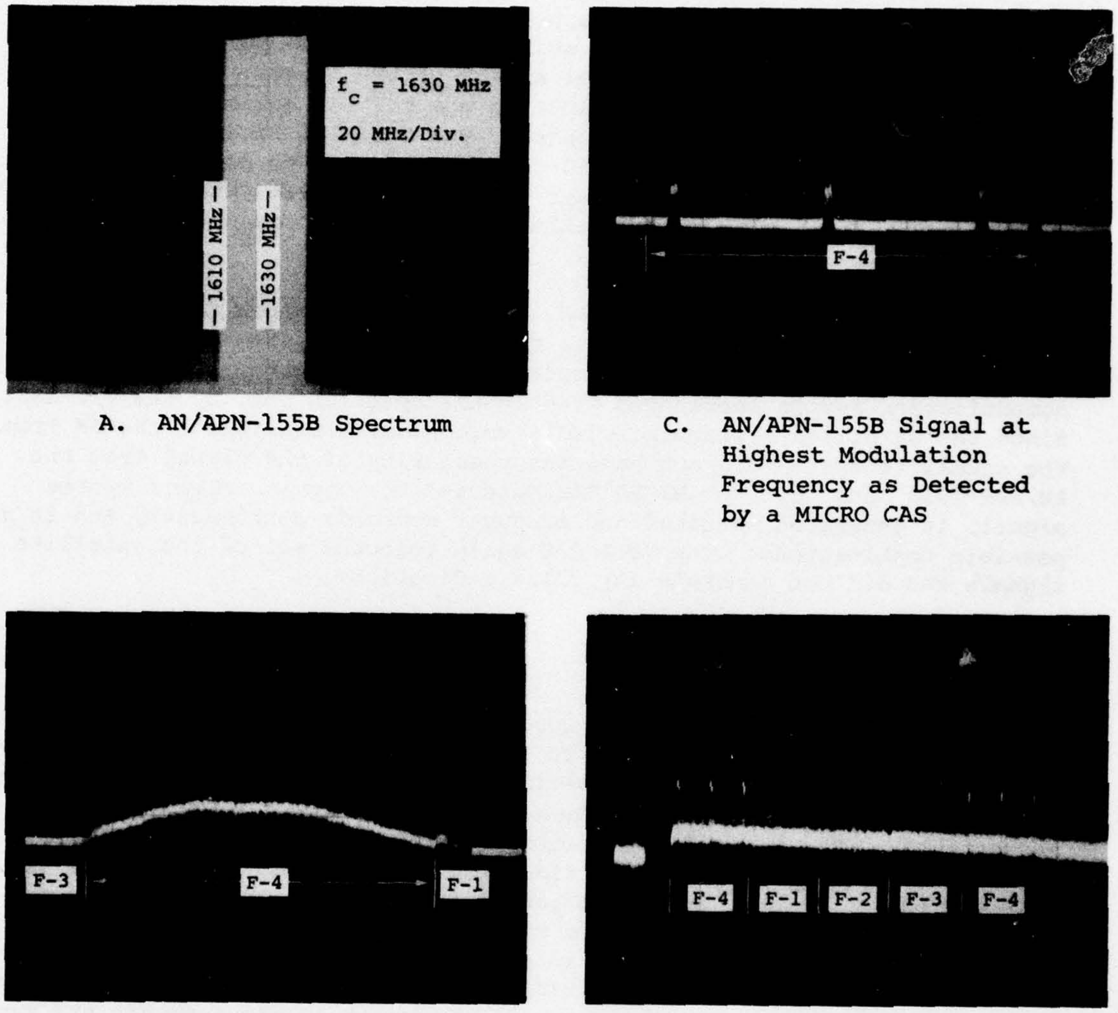


B. AN/APN-159A Spectrum
Low Altitude Mode



C. AN/APN-159A Pulses as
Detected by MICRO CAS
Receiver

Figure 4-2. AN/APN-159A RADAR ALTIMETER



A. AN/APN-155B Spectrum

B. AN/APN-155B Signal at Lowest Modulation Frequency as Detected by a MICRO CAS

C. AN/APN-155B Signal at Highest Modulation Frequency as Detected by a MICRO CAS

D. AN/APN-155B Signal Appearing in Consecutive F-4 Time Slots

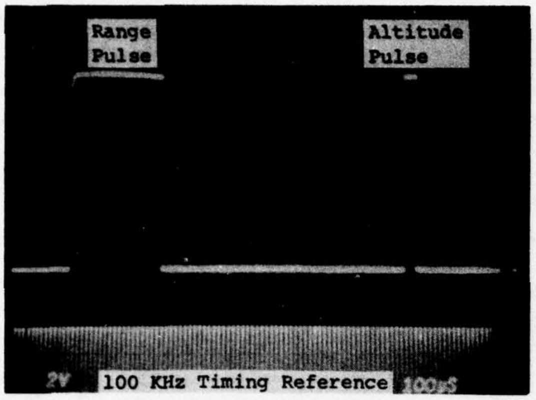
Figure 4-3. AN/APN-155B RADAR ALTIMETER

appearance increases until it is appearing in every F-4 time slot as a single pulse, then as two pulses, and finally as three pulses as shown in photographs C and D. The principal effect of the AN/APN-155B signals is to completely deny the F-4 time slots to the T/F CAS equipments by making all of the slots appear to be occupied. The FULL CAS invariably rejects all of these signals, but the MICRO CAS was observed to occasionally generate a false warning or maneuver command. The MICRO CAS could be made as resistant as the FULL CAS by making its signal-acceptance criteria more selective.

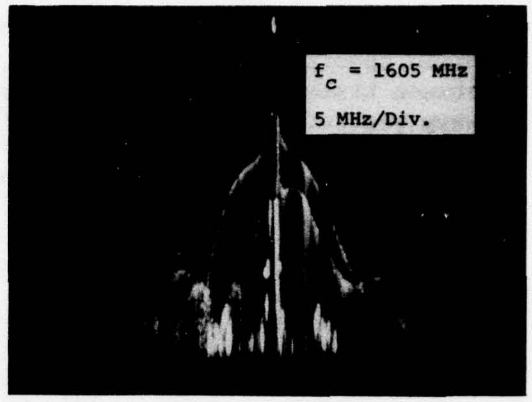
The ITS test program conducted at the ARINC Research facilities included an interference test of a satellite communications system that employed frequency modulation as one mode of operation. The spectrum of the satellite communication system overlapped greatly the spectrum used by the T/F CAS. Since the satellite system included a voice-modulated signal, the FM from the satellite system did not have the regularity of the signal from the AN/APN-155B, and when the MICRO CAS detected the communications system signal, it generated warnings and maneuver commands continuously and in all possible combinations. The FULL CAS again rejected all of the satellite signals and did not generate any false indications.

4.4 CAS SPECTRUMS

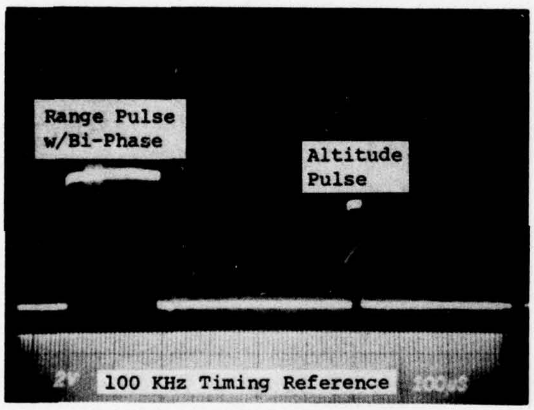
Photographs of the radiated spectrums of the T/F CAS equipments were made to see if they were meeting the ANTC 117 requirements and to compare them with the spectrums of the radar altimeters. The signals transmitted by the MICRO CAS and the FULL CAS are shown in Figure 4-4, photographs A and B, respectively. The MICRO CAS transmits two CW pulses, once every three seconds. The first pulse is 200 microseconds long, the second pulse is 25.6 microseconds long, and the pulses are about 700 microseconds apart, leading edge to leading edge. The signal at the bottom of the photograph is a 100-kHz timing signal inserted as a reference. The FULL CAS signal is the same as the signal of the MICRO CAS except that the 200-microsecond pulse includes biphase modulation,which starts at 40 microseconds and may extend to 160 microseconds. In addition, the FULL CAS transmits epoch-start triads in the first slot of every other epoch. The triad is three pulses of 1.6 microseconds each, spaced eight microseconds between the first and second and 9.6 microseconds between the second and third. The MICRO CAS shown is transmitting on F-2; thus the center frequency is 1605 MHz. The photograph shows that the spectrum is double, with the inner envelope being the spectrum of the 200-microsecond range pulse and the outer envelope being the spectrum of the 25.6-microsecond altitude pulse. The short bright lines at 1600, 1605, and 1610 MHz are leakage from the receiver local oscillator. The FULL CAS spectrum is shown in photograph D. The CAS was using an F-4 as own slot and an F-3 as future slot and was transmitting epoch starts on F-1. In the photograph the bright envelope with the peak on the right is the F-4 own-slot spectrum. The faint peak on the left was generated by the epoch-start transmissions. Only two faint lines at the center of the photograph are evidence of the occasional transmissions in the future slot on F-3.



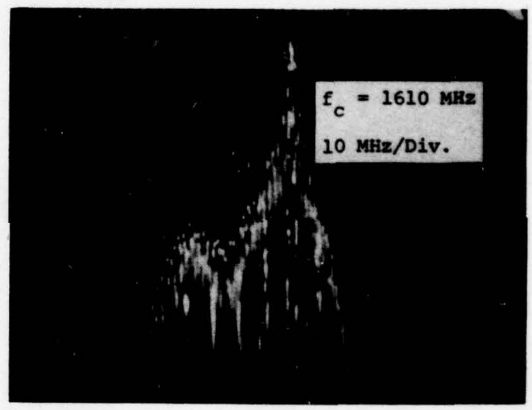
A. MICRO CAS Transmitted Signal
100 μsec/Div.



C. MICRO CAS Spectrum Own Slot on F-2 (1605 MHz)



B. Full CAS Transmitted Signal
100 μsec/Div.



D. Full CAS Spectrum Own Slot on F-4 (1615 MHz)
Future Slot on F-3 (1610 MHz)
Epoch Start on F-1 (1600 MHz)

Figure 4-4. T/F CAS TRANSMITTED SIGNALS AND TRANSMISSION SPECTRUMS

The lowest sweep spread of the spectrum analyzer was much too fast to obtain spectrums from the T/F CAS because of the three-second interval between transmissions. Therefore, it was necessary to design an external sweep generator that could provide nearly linear sweeps at very low rates. The circuit used to provide the external sweep is shown in Figure 4-5. The bias voltage for the 3N128 insulated gate FET, Q1, is provided by C1, a 500-volt electrolytic capacitor. The very high input impedance of Q1 permits the discharge of C1 to be controlled by Rs. Values of Rs between 5 and 9 megohms provided sweep times from 25 minutes to 45 minutes. The value of R_L was selected to yield full-scale sweep position of nine volts while the discharge of C1 was still in the linear portion of the discharge curve. The current-limiting resistor, R_c, can be any value that provides adequate control when recharging C1. The voltmeter indicates the position of the sweep and is used to tell when the sweep is completed. To use the circuit, the capacitor is charged until the voltmeter reads zero; then the shutter of the camera on the spectrum analyzer is opened and left open until the voltmeter shows that the sweep has been completed. The spectrum analyzer must be used in the non-memory mode.

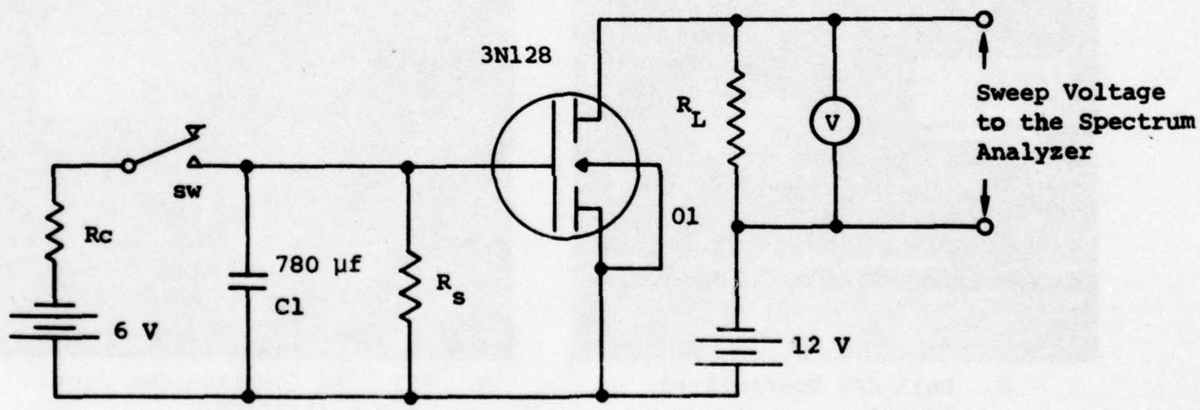


Figure 4-5. EXTERNAL SWEEP CIRCUIT FOR SPECTRUM ANALYZER

4.5 SIMULATED INTERFERENCE FROM HELICOPTER ROTORS

To determine if helicopter rotors would cause communications dropouts in the CAS signals, a simulated rotor was placed between a directional transmitting horn antenna and the CAS receiving antenna. The antennas were separated about six feet and the rotor (a sheet metal blade) was spun at 12 rpm. No appreciable degradation of the signal was observed as long as the received signal strength was sufficient for normal operation; the rotor blade seemed to make little difference except for an occasional data drop-out. A significant amount of multipath reception occurred in the laboratory from the steel frame construction and prevented the test from being as severe as possible. Nevertheless it is believed that the T/F CAS will perform satisfactorily in helicopter applications.

4.6 TIME-SLOT SELECTION

A series of tests was conducted under controlled conditions to identify patterns of slot selection by the FULL CAS and the MICRO CAS and to examine their behavior when the number of time slots available was small or was insufficient to accommodate all of the operating systems. They were also conducted to determine whether a FULL CAS, by virtue of using a future slot when testing for co-occupants, effectively occupied two time slots. The tests were conducted by using a T&E unit as a ground station and a traffic simulator as a slot filler. The T&E could be made to occupy any slot desired, and the traffic simulator could "fill" any number and pattern of slots desired.

From the tests it was found that the FULL CAS may select any time slot available but that the examples tested tended to select an early slot. If driven out of their time slot, they always shifted to their future slot and then selected still another time slot as a "new future slot". A FULL CAS that is forced out of its future slot tends to select a new future slot in close proximity to the time slot it is using as "own slot". The "new future slot" may be an earlier, as well as a later, time slot than "own slot."

If two FULL CAS's have four time slots available, two slots will be used as own slots and the other two slots will be used as future slots. If there are only three slots available, two slots will be used as own slots and the remaining slot will be shared as a future slot. If only two slots are available, they will be used as own slots and future slots will not be selected. Thus FULL CAS's effectively occupy two slots only as long as there are enough slots available to permit each to have an own slot and a future slot.

If all slots are being used as own slots so that there is no vacant slot to shift to, a FULL CAS will not vacate its own slot upon the appearance of a co-occupant. Thus the FULL CAS will have unilateral protection against all aircraft except the co-occupant as long as it can remain in the synchronized mode. This probably will not be very long because fine-synchronization replies will be inhibited by any donor that hears both of the co-occupants.

The MICRO CAS transmits on only one frequency and always selects the first available time slot on its frequency. If forced out of its time slot, it will select the next available slot on its frequency. If there are no unoccupied time slots available on its frequency, a MICRO CAS will go into a continuous search mode during which it tests each successive slot on its frequency but does not transmit in any of them. If any of the occupants on its frequency tests for co-occupancy, the MICRO CAS will adopt that slot and the two will become co-occupants until one of them again tests for co-occupancy.

If a FULL CAS and a MICRO CAS are contending for a single available time slot, the FULL CAS will invariably seize the slot from the MICRO CAS when the MICRO CAS tests for co-occupancy. If there were more FULL CAS's and MICRO CAS's within mutual communication range than there were time slots, the FULL CAS's would be ensconced, each in an own slot, and the MICRO CAS's would in effect be "playing a gigantic game of musical chairs" in the remaining slots by virtue of the technique the MICRO CAS uses for co-occupancy detection. Two MICRO CAS's that are co-occupants may cease to receive fine synchronization, but they will not revert to standby mode as long as they are receiving coarse synchronization. When one is forced out of the slot as a result of having detected the co-occupant, the other MICRO CAS will again begin receiving fine synchronization. The saturated condition described will cause very little loss of collision protection. The co-occupants will not be protected against each other, and, if the co-occupants are only a few miles apart, a third aircraft will not have mutual protection against the co-occupants, but the co-occupants will have unilateral protection against the third aircraft.

4.7 MEASUREMENT OF EVENT PULSE TIME DELAYS

The FULL CAS that was interfaced with ATA instrumentation generates pulses that mark the time of occurrence of events during operation. Each of these event pulses is provided with its own wire to the ATA instrumentation. The ATA instrumentation measures the time of occurrence and records it, with the identity of the event, on magnetic tape. The recorded times are computer-processed to calculate the range, range rate, altitude, etc., that these event times represent so that they can be compared with the actual data as obtained from other sources such as altimeters and radar tracking. The event pulses are not generated simultaneously with the event they represent, and the generation delay is not the same for all types of event pulses. In addition, the delay from generation of the pulse to arrival of the pulse at the ATA instrumentation was not the same for all types of pulses. Therefore, it was necessary to measure the delays and insert them in the computer program.

Events occur in T/F CAS operation always with respect to the beginning of a time slot. The time reference at the start of each time slot is a pulse that is generated 15 microseconds after the beginning of the slot. This pulse is called t_o (little tee). All event-pulse delays at the ATA instrumentation were measured with respect to the time the t_o reference pulse arrived. The delays were measured for the following event pulses:

a. Range pulse transmitted

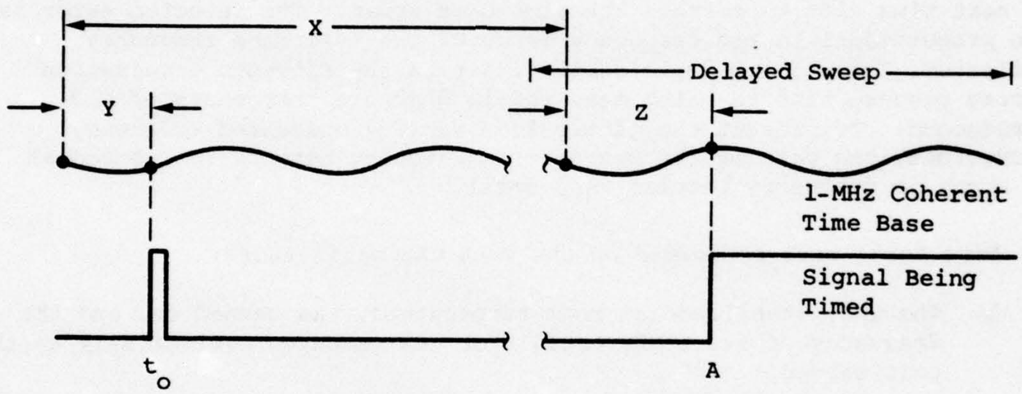
b. Range pulse received

c. Altitude pulse transmitted

d. Altitude pulse received

An attempt to measure the delays with a high-speed counter was unsuccessful because the uncertainty in trigger level of the counter caused

greater variation in the readings than could be tolerated. The technique finally arrived at involved the use of a cesium-beam oscillator with a stability of 1×10^{-11}, and a dual-beam oscilloscope with a delayed-sweep capability. The cesium-beam oscillator was used to synchronize the CAS, and the 1-MHz output was displayed on one trace of the oscilloscope. The oscilloscope was externally triggered by t_o from the CAS, and t_o as received by the ATA instrumentation was displayed on the lower trace as shown in the left-hand part of Figure 4-6. The time coherence between the trigger, t_o from the CAS, and the 1-MHz time base on the upper trace permitted the precise position of the pulse to be determined. The pulse being timed was then displayed on the lower trace, and by means of the oscilloscope sweep delay its precise position could be determined and the delay could be calculated as shown in the figure.



Time Delay Between t_o and Event Pulse A Equals X - Y + Z

Figure 4-6. MEASURING EVENT PULSE DELAY TIMES

The timing corrections measured are summarized in Table 4-1.

Table 4-1. TIMING CORRECTIONS FOR SIGNAL DELAYS

Signal Measured	T&E	CAU
Range Pulse Transmitted	0.0	+0.3 μsec.
Altitude Pulse Transmitted	Not Applicable	+0.3 μsec.
Range Pulse Received*	+0.3 μsec.	+0.4 μsec.
Altitude Pulse Received*	+0.3 μsec.	+0.4 μsec.

*Delay varies with received signal strength. The values given are for strong signals (-30 dBm or greater).

4.8 OSCILLATOR FREQUENCY STABILITY AND FREQUENCY SYNCHRONIZING ACCURACY

During the flight testing it was observed that the oscillator installed in the full CAS was much more stable than required by the ANTC 117 specification. As a result, the hierarchy rundown rate, which is based on the specified stability, greatly underutilized the performance capability of the oscillators. Therefore, it was decided to conduct a brief test of the oscillators in the laboratory to quantize the observed performance.

In the design of the T/F CAS, both time-base synchronization and reference-frequency corrections are obtained from the fine-synchronization replies at 1419.2 microseconds after the start of the time slot. The time difference between reply receipt and zero-error time is twice the error in the time-base. The detected error is then applied to the time of starting the next time slot to correct the time-base error. The detected error is also proportional to the frequency error of the reference frequency oscillator. There is an unavoidable jitter in the fine-synchronization process because time is being measured in discrete increments of 0.2 microsecond. To prevent the jitter from causing undesired frequency corrections, the gain of the frequency-correcting network is reduced as the error in frequency becomes very small.

Five tests were performed on the FULL CAS oscillators:

1. The CAS, stabilized at room temperature, was turned on, and the frequency of its 5-MHz oscillator was measured periodically as the unit warmed.
2. After a 20-minute warm-up time, the CAS was given fine-synchronization support for three minutes. Then support was withdrawn and the time-base drift was monitored until the maximum permissible error of two microseconds had accumulated.
3. A CAS that had been operating for two hours with an extended period of fine-synchronization support was observed until the instrumentation indicated that a fine-synchronization reply with maximum jitter effect had been received. Fine-synchronization support was then terminated, and time-base drift was monitored to determine the effect when synchronization support ended after a large jitter error.
4. A CAS that had been operating for six hours was given fine-synchronization support for 10 minutes. Then support was withdrawn and the time-base drift was monitored.
5. A CAS unit that had not operated for two months and had been subjected to considerable handling was warmed for 40 minutes and then was given fine-synchronization support for 10 minutes. Synchronization support was withdrawn and the time-base drift was monitored.

The results of the tests are shown in Table 4-2.

Table 4-2. OSCILLATOR STABILITY TEST RESULTS		
Test	Conditions	Results
1	Cold start-up, no fine-synchronization support	Time (min.) / Freq. Error 0 / +11 Hz 1.5 / -3 Hz 5 / -0.2 Hz 6 / -0.0 Hz 7 / +0.2 Hz 8 / +0.2 Hz 9 / +0.3 Hz
2	Twenty-minute warm-up, three minutes of fine-synchronization support	Time-Base Drift Rate 1.5×10^{-9}
3	Two-hour warm-up, synchronization support withdrawn after maximum jitter error	2.5×10^{-10}
4	Six-hour warm-up, 10 minutes of fine-synchronization support	2.2×10^{-11}
5	Two-month non-operation, cold start, 40-minute warm-up, 10 minutes fine-synchronization support	2×10^{-10}

These results confirmed the observations made during the flight testing. For the time-base drift rate obtained in Test 2, the time to accumulate two-microsecond error would be 22 minutes, and at the time-base drift rate obtained in Test 3, the time would increase to two hours, 13 minutes. These results indicate that the hierarchy rundown time could be extended considerably beyond the four minutes currently used.

The MICRO CAS oscillator is not encased in a temperature-stabilizing oven, and the frequency-correcting circuitry makes much larger corrections than does the correcting circuitry in the FULL CAS. Thus the MICRO CAS oscillator is not gently forced onto the correct frequency but is instead continually stepped in small increments about the correct frequency. These oscillators were tested in the same manner as were the oscillators in the FULL CAS, but because of the stepping by the frequency-correcting circuitry, the results were somewhat chaotic. It was established that the frequency accuracy under continuous fine-synchronization support was slightly better than 1×10^{-8}. This performance does not exceed specification enough to warrant extending the present time of 2-1/2 minutes of synchronized operation subsequent to loss of fine-synchronization support.

4.9 VERIFICATION OF MALFUNCTION OBSERVED DURING THE FLIGHT TESTING

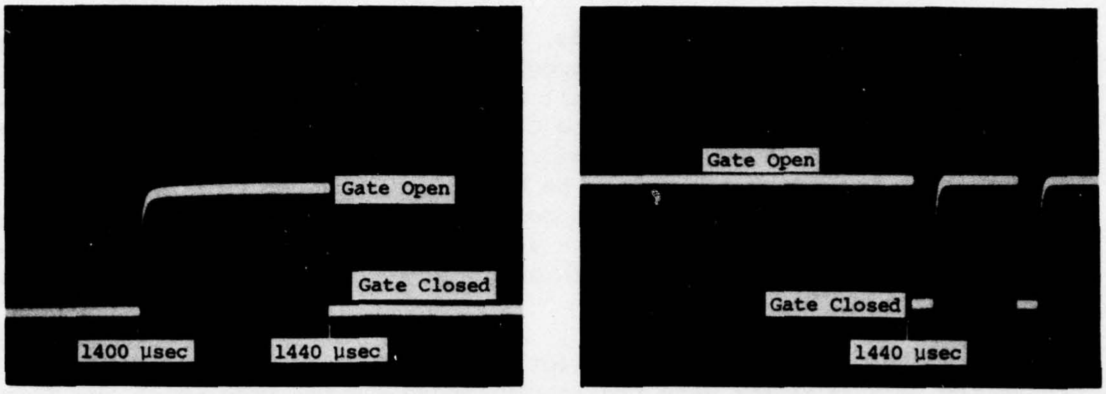
The FULL CAS installed on the C-131 (819) aircraft twice experienced a skewing of its time base during the test flight conducted on 26 March 1973. The cause of the time skew was a malfunction of the fine-synchronization gate, which permitted acceptance of a false fine-synchronization reply. The malfunction is fully explained in Chapter Five. Only the process used to verify the malfunction is described here.

When the computer run from the ATA instrumentation tape was examined, it showed two instances of early fine-synchronization replies followed by rundown of hierarchy into backup mode and subsequent resynchronization. The video tapes from the MICRO CAS's were examined, and they showed that the suspected system was the one that developed the time skew. It was hypothesized that the fine-synchronization gate was the problem. The laboratory test was designed to test that hypothesis.

The unit that had malfunctioned, the T&E system, and another full system were interconnected on the bench so that they could all communicate with each other. The second full system had the ground-station logic card installed so that it could keep the full system that was undergoing test in the synchronized mode. All systems were synchronized; then the exciter of the T&E was shorted to inhibit transmission and its oscillator frequency was offset so that its apparent range to the other units would drift. When the range reached 48 nautical miles, which corresponds to the time error observed, the ground-station FULL CAS was inhibited and synchronization support was shifted to the T&E, and it then became the new ground station. The fine-synchronization replies from the T&E arrived at the FULL CAS undergoing test 600 microseconds early and would have been ignored if the fine-synchronization gate had been functioning properly. The fine-synchronization replies were promptly accepted, and the FULL CAS synchronized itself to the T&E, thus corroborating the fact that the fine-synchronization gate was improperly open at the time the reply arrived. Synchronization support was shifted back to the FULL CAS ground station and, because of the misalignment of its time base by 300 microseconds early, the FULL CAS undergoing test could not obtain fine synchronisation. It had to run down in hierarchy and enter back-up mode to become resynchronized in exactly the same manner observed in the test flight.

The test was repeated at longer and at shorter apparent ranges. At ranges slightly longer than 48 nautical miles the early replies were not accepted because the receiver had not recovered sensitivity following transmission of the altitude pulse. Early replies were accepted at all ranges less than 48 nautical miles.

The logic output of the fine-synchronization acceptance gate was displayed on an oscilloscope and found to be open continuously until after the time it was supposed to reclose. The correct gating is shown in Figure 4-7, photograph A. The gate opens at 1400 microseconds and closes at 1440 microseconds. Photograph B shows that the malfunctioning gate is open until 1440 microseconds, then is closed for two periods of six microseconds each.



A. Normal Fine Sync Gate Timing 10 μsec/Div.

B. Malfunctioned Fine Sync Gate Timing 10 μsec/Div.

Figure 4-7. FULL CAS FINE-SYNCHRONIZATION GATE MALFUNCTION

The fault was determined to be a bad solder joint on a flip-flop pack. Resoldering the joint restored the gating to proper operation. The tests were repeated after the repair, and the CAS rejected all replies arriving earlier than 1400 microseconds..

4.10 INVESTIGATION OF OPERATING ANOMALIES OBSERVED DURING THE SUPERSONIC TEST OF BACK-UP MODE

The film from the supersonic backup-mode test flight revealed that the FULL CAS's being tested decoded a large number of epoch-start triads. The transmission of epoch-start triads by the ground station had been inhibited; therefore, the epoch starts appearing on the film were from one of three possible sources: (1) decoded noise pulses, (2) malfunctions in the CAS's, or (3) malfunctions in the instrumentation sets. Since simultaneous and identical malfunctions in the CAS's or the instrumentation sets were highly unlikely, it was hypothesized that the epoch starts were decoded noise pulses. It was noticed that the antennas had been installed in close proximity to the rotating beacons. Since the d-c motors contained in rotating beacons are known to radiate a spectrum of spike-like noise, the beacons were suspected to be the source.

To verify this hypothesis in the laboratory, the motor from a rotating beacon was run in close proximity to the CAS antenna. The position of the motor was adjusted until noise spikes were observed in the video output from the CAS receiver. The T&E was operated as a ground station but the transmitter of the CAS was inhibited so that it could not obtain fine synchronization. The instrumentation was monitored for indications of epoch-start recognitions. It was observed that epoch-start triads were decoded from noise in approximately 50 percent of the epochs. The CAS logic requires two epoch starts to be recognized, separated by six seconds

plus or minus a few microseconds, before accepting the epoch starts as authentic. Acceptance of the epoch starts as authentic could be identified by a change from an all-call synchronization request to an addressed synchronization request. If the CAS had accepted false epoch starts as being authentic, it would have addressed the T&E for fine synchronization, but in an erroneous address. The CAS never accepted as authentic any epoch-start triads decoded from noise. Authentic epoch starts were being supplied by the T&E operating as a ground station. These authentic epoch starts were always recognized in about 10 epochs or less after the CAS began looking for epoch start.

It was concluded that the rotating beacons on the F-106 aircraft used in the test programs were the sources of the noise from which the false epoch starts were decoded. The presence of these noise pulses does not seriously interfere with the process of obtaining synchronization, but it does extend the time the process requires from a few seconds without noise to up to a minute with noise. However, the presence of noise of this character and signal strength seriously interferes with the operation of the T/F CAS by causing the rate of rejection of genuine CAS signals to become higher than can be tolerated. This increase in rejection rate was discovered when the data from the F-106 flights were being reduced.

CHAPTER FIVE

SPECIAL PROBLEMS ENCOUNTERED DURING THE T/F CAS TEST PROGRAM

In the course of the flight testing several events and conditions created additional complication in processing the collected data, disclosed the need for further investigations, or prompted the development of special procedures:

- AN/APN-155B radar altimeter interference with the operation of the ground station
- Epoch-start triads decoded from noise most likely generated by the anti-collision rotating becon light
- The fine-synchronization gate malfunction on FULL CAS serial number 2
- The intermittent malfunction in the altitude decoder of MICRO CAS serial number 3

In this chapter the impact of these occurrences is discussed and the corrective measures taken are explained. The associated problems discussed separately in this chapter were important to the overall flight-test effort; however, they do not represent inherent flaws in the T/F CAS concept. In every case the problems were due to CAS hardware problems or failures and not logical oversights in the CAS concept.

5.1 AN/APN-155B INTERFERENCE WITH GROUND STATION OPERATION

The discovery that T/F CAS equipments could be affected by the AN/APN-155B radar altimeter was an unexpected result of the flight-test program. While this will be important if the AN/APN-155B is allowed to continue to operate in the CAS frequency spectrum, the main effect on the test program was to necessitate a modification in the method of keeping the aircraft synchronized.

The Test and Evaluation (T&E) model of the T/F CAS that was used as a ground station during the flight testing was built in 1969 for the experimental flight-test program sponsored by the Air Transport Association. The transmitter in the T&E has a fairly low limit on the maximum average power that can be radiated without overstressing of the transmitter. Therefore, the transmitter was designed to stay within the power limitation by

automatically and progressively reducing the transmitted peak power as the transmitting duty cycle increased beyond the highest duty cycle at which full peak power could be maintained safely. The power requirements for the ground station (for the number of aircraft involved in the flight-test program) were well within the power limitation of the T&E transmitter. However, the T&E had an independent capability incorporated in its logic circuit that kept track of the apparent number of aircraft by counting the number of time slots that were filled, and when this number went above a set limit, the equipment would suppress its fine-synchronization replies to all aircraft.

The signal transmitted by the AN/APN-155B has the effect of filling all of the time slots that use the F-4 frequency. Thus, when the T&E sensed the signals from the AN/APN-155B radar altimeter on transient F-4 aircraft, it saw 500 "aircraft" occupying the F-4 time slots and it suppressed fine synchronization to the T/F CAS equipments on the test aircraft. If this condition had persisted long enough to allow the airborne FULL CAS's to demote into back-up mode, it would have seriously disrupted the test in progress.

The method selected to solve the problem was to modify one of the FULL CAS's by inserting a switch in the sense line that informs the CAS that it has an atomic oscillator precision-frequency unit (PFU) as a frequency reference. When an AN/APN-155B caused the T&E to suppress fine-synchronization support, this switch was placed in the PFU position to slow the demotion rate so that the modified unit would stay in the synchronized mode and provide fine synchronization to the other airborne systems until the ground station could resume support. This solution worked better than expected because the crystal oscillator in the FULL CAS considerably exceeds the specification for frequency stability.

As a result of the experience with the AN/APN-155B, the laboratory testing following the flight tests was expanded to include interference testing of the AN/APN-155B. As stated in the chapter on laboratory testing, it was found that the engineering model T/F CAS is not affected by the AN/APN-155B in the same manner as the Test and Evaluation ground station. Because ground stations built in the future will use this improved logic, no interruption of fine-synchronization support from a deployed ground station should be caused by AN/APN-155B signals.

5.2 EPOCH-START TRIADS DECODED FROM NOISE

The supersonic missions revealed that the T/F CAS equipments can be affected by the rotating beacon light. The impact on the test program is discussed below.

The epoch-start triads that were decoded from noise during the F-106 back-up mode flight test caused the epoch count numbers, as shown by the ground station and by the instrumentation in the two aircraft, to become misaligned. The magnitude of the problem of realigning the epochs was not fully realized until the data were being prepared for analysis.

After extensive analysis of the data it was deduced that the epoch count display was stepped each time an epoch start occurred, whether the epoch start was internally generated by the CAS or was decoded by the logic. Thus the decoding of epoch starts from noise caused the stepping of the counter to occur progressively earlier, until finally a full extra count was accumulated. On the other hand, the time-slot counter in the instrumentation was reset only by the epoch-start signal generated internally by the CAS. This difference in the operation of the two counters provided the key to realigning the data.

Each time a false epoch-start triad was detected, the CAS would reset its internal time-slot counter to zero. When the counter again reached the number of "own-slot", the CAS would transmit and the instrumentation would display the count that was at that moment in the instrumentation time-slot counter. Since the time-slot counter in the instrumentation was not reset by the false epoch start, the displayed number was not the number of the time slot that the CAS was using as own-slot. By subtracting the correct number for own-slot from the number displayed for own-slot, the point in the epoch at which the false epoch start was recognized could be calculated and the relative positions of epoch start in the two aircraft could be adjusted. As an example, EROS 4 was using time slot 80 as own-slot, but in one frame the number displayed was 340. The chronology of this event was as follows: At the beginning of the epoch, which will be called 200 for convenience, the epoch counter was stepped from 199 to 200; the CAS slot counter and the instrumentation slot counter were reset to zero. When the CAS slot counter reached 80, the CAS transmitted, and the number 80 was strobed into the instrumentation display. In slot 260, the false epoch start was recognized, the CAS slot counter was reset, and the epoch counter was stepped to 201; but the instrumentation slot counter stayed at the number 260. When the CAS slot counter again reached 80, the CAS again transmitted and the number in the instrumentation slot counter was strobed into the display; but that slot counter was then reading 340. Thus the own-slot display showed that the EROS 4 time base had been shifted with respect to the time bases of EROS 5 and the ground station by 1740 time slots (2000 minus 260).

The realignment was accomplished by locating as many points in the data as possible in which the epochs in the two aircraft were starting at nearly the same time as evidenced by correct, or nearly correct, display of the other aircraft's time slot, and then working both ways from these points until all of the data agreed. The magnitude of the task can be appreciated from the fact that in one series of 64 epochs there were six time-base realignments by EROS 4 and 16 time-base realignments by EROS 5.

5.3 FINE-SYNCHRONIZATION GATE MALFUNCTION

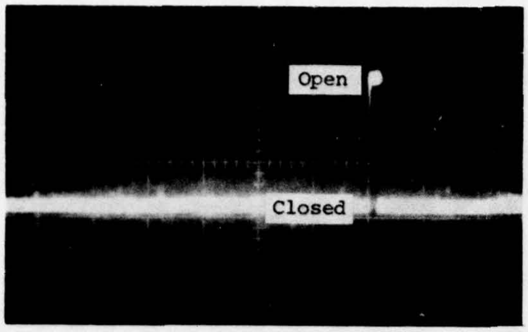
At the times of occurrence of the time-base skews of FULL CAS serial number 2 on C-131 (819) there were conflicting indications as to what had happened and which of the full systems had malfunctioned. Following the flight all the CAS equipments were checked and no problems were found in them. It was realized that it would require a careful examination of the

data to find the cause of the time-base skew and to reconstruct the event. With the equipments apparently operating properly and the test flights almost complete, it was decided to continue the test flights and to postpone the search for the cause until the data were to be evaluated. Fortunately, the remaining flights were completed without the problem occurring again. In the laboratory it was learned that the time-base skew problem was the result of a failed solder connection and not a basic flaw in the T/F CAS concept.

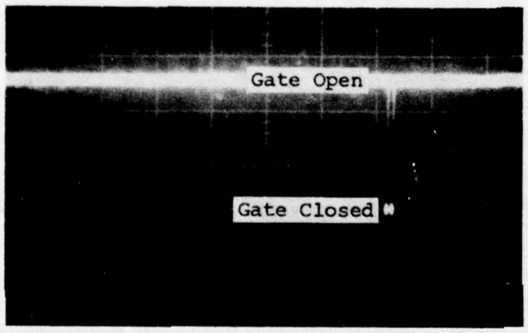
The time-base misalignment was traced to a failed solder joint in the logic circuitry that controls the timing of the acceptance gate for fine-synchronization replies. The normal timing of the gate is shown in photograph A of Figure 5-1. The gate is normally open for 40 microseconds, starting at 1400 microseconds and ending at 1440 microseconds. Because of the fault in the logic the gate was functioning as shown in photograph B. The gate was continuously open except for two six-microsecond intervals at 1440 microseconds and 1460 microseconds. As a result of the improperly open gate, the system accepted a "fine-synchronization reply" that was decoded at 813 microseconds and misaligned its time base by approximately 300 microseconds.

A photograph showing the time that the misalignment occurred was made from the video tape recorded from the MICRO CAS installed on the same aircraft, C-131 (819). The tape was recorded from an upper antenna, and since the epoch was a ground epoch, the FULL CAS was using its bottom antenna, so that the signal seen by the MICRO CAS was not identical to that seen by the FULL CAS. The signal seen by the MICRO CAS is shown in photograph C. The large pulse at the left is the altitude pulse from the FULL CAS. The next pulse is a reflection of the altitude pulse from an object at about three nautical miles. The return is too early to be the source of the falsely decoded fine-synchronization reply. The squiggle beginning at 75 microseconds in the photograph is grossly unlike a fine-synchronization triad and so is not the cause either. The area in which the FULL CAS decoded the fine-synchronization triad reply is the last 20 microseconds of the photograph, and the MICRO CAS (upper antenna) saw no signal at all in this area.

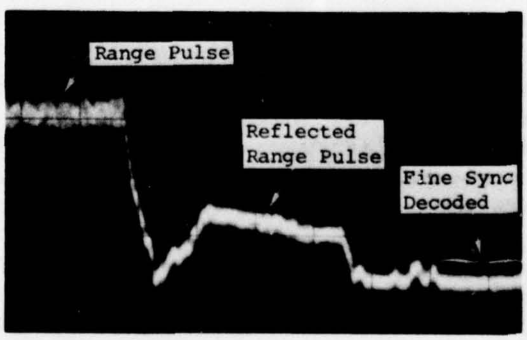
In the next epoch the time-skewed FULL CAS transmitted a fine-synchronization reply to the MICRO CAS on C-131 (819), which was properly timed to its skewed time base but was early by system time. This reply, photograph D, was accepted, and the MICRO CAS time base became skewed. Photograph E shows the early fine-synchronization reply and a properly timed reply from the FULL CAS on C-131 (804). The skewed FULL CAS tried to skew the MICRO CAS on C-131 (804), as shown in photograph F from video tape recorded from that MICRO CAS. The photograph shows the MICRO CAS's altitude pulse, the early fine-synchronization reply, and a properly timed reply from the FULL CAS on C-131 (804). The "signal" at the extreme right is a transient caused by switching the receiver to the next frequency. This early reply was rejected because of the short pulse shown in photograph G. The first pulse of the triad was short because the MICRO CAS receiver had not recovered full sensitivity following transmission of



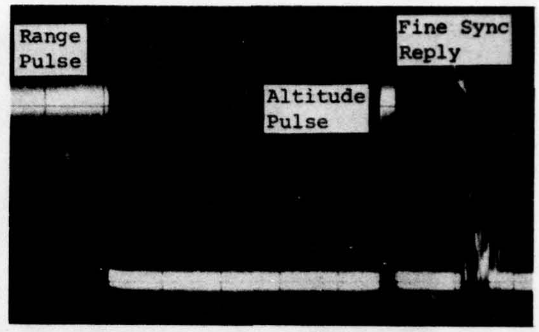
A. Normal Fine Sync Gate Timing
100 μsec/Div.



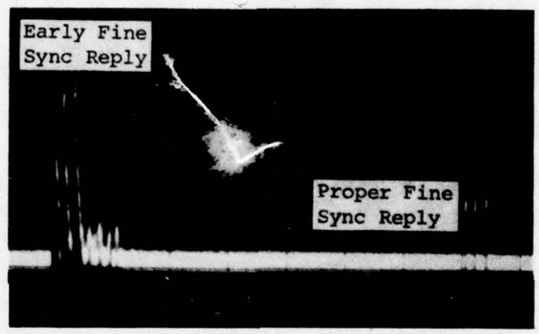
B. Malfunctioning Fine Sync Gate Timing
100 μsec/Div.



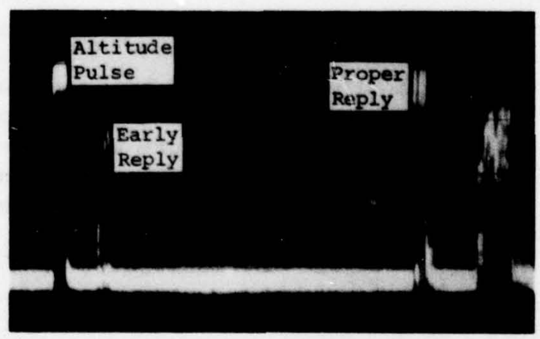
C. Time of False Fine Sync Decoding - Seen by Upper Antenna
10 μsec/Div.



D. Early Fine Sync to MICRO CAS C-131(819)
100 μsec/Div.

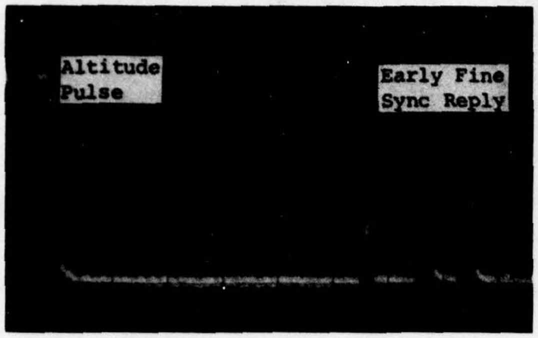


E. Early Fine Sync and Correct Fine Sync
50 μsec/Div.

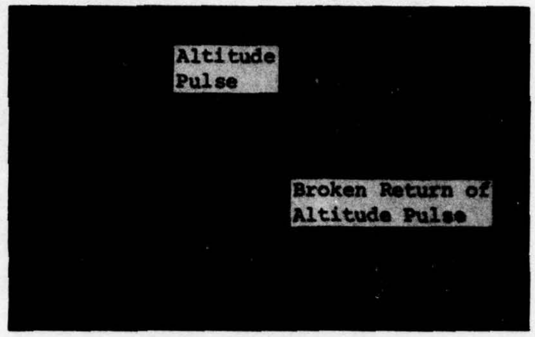


F. Fine Sync Replies to MICRO CAS C-131(804)
100 μsec/Div.

Figure 5-1. FINE SYNCHRONIZATION GATE MALFUNCTION FULL CAS SN-2 (continued)



G. Enlargement of Photograph F
10 μsec/Div.



H. Altitude Pulse and Broken Return
20 μsec/Div.

Figure 7-1. (continued)

its altitude pulse. About 40 minutes after the first occurrence, the FULL CAS on C-131 (819) again became time-skewed in precisely the same way as the first occurrence. The only change was that this time both MICRO CAS's were "captured" and became skewed.

Photograph H shows the time of the second acceptance of a false fine-synchronization reply. This photograph is included because it shows how an altitude pulse can be reflected back in a broken form that could satisfy the acceptance criteria for fine-synchronization replies.

5.4 INTERMITTENT MALFUNCTION IN THE ALTITUDE DECODER

During the flight test, anomalies in the altitudes transmitted and read by MICRO CAS serial number 3 installed in C-131 (804) went unobserved. Since the CAS uses pressure altitude and the aircraft were flying at true altitudes, differences were expected between the assigned altitude and the CAS readings; hence the differences were ignored.

While the statistics of CAS altitude measurement were being developed, it was seen that there were inconsistencies in the results that were not attributable to differences in performance of the respective equipments. It was noted that when the results indicated poor performance, one of the equipments involved was always MICRO CAS serial number 3; but it was also noted that for some blocks of data the performance of that unit was consistent with the performance of the other units.

Several theories were developed, tested, and disproved before the "correct" theory was found. It was finally recognized that there was a pattern to the erroneous altitudes that was consistent with a reversal in

the C1 and C4 bits in the altitude code of the encoding altimeter. After a substantial number of data points were checked and it was found that they all fitted the reversed-bit theory, it was speculated that there was a wiring reversal inside the unit. This theory was presented to the McDonnell Douglas engineers, with the request that they check the unit. They were skeptical about the wire-reversal theory but were also anxious to find the cause of the erroneous altitudes.

No wiring error was found; therefore, the unit was operated on the bench under close observation. Prolonged observation revealed that the unit would intermittently decode altitude incorrectly. The fault was traced to a flip-flop that is used to decode the C1 and C4 bits. These bits never both appear in an altitude code; thus a flip-flop was chosen as the logic element to detect which was present when the code included a C1 or C4 bit. When the flip-flop malfunctioned, it caused a reversal of the bit that was indicated to be present. When a C1 or C4 bit was present and the malfunction existed, the decoded altitude was in error by 200 feet or by 400 feet, depending on whether the C2 bit was or was not also present. After the intermittency of the malfunction was identified, the data were reexamined and, with the new knowledge, the good-bad change points could fairly easily be recognized.

For the development of the statistics of altitude measurement, it was intended to purge the data base of all the incorrectly decoded altitudes. Because of the intermittent nature of the malfunction, it is possible that some small number of such points were included in the statistical evaluation.

CHAPTER SIX

DISCUSSION OF THE T/F CAS TEST-PROGRAM RESULTS

All of the objectives of the Test Plan for the Evaluation of the Time/Frequency Collision Avoidance Concept were met in the test program; in addition, several unanticipated problem areas were uncovered and investigated. Chapters Three and Four provide detailed data on the flight-test program and the laboratory test activity, this chapter summarizes the major results of these two efforts.

6.1 T/F CAS ERRORS, WARNINGS AND ALARMS

The major objective of the CAS test program was to determine the inherent errors in the CAS concept. The errors in CAS measurement of range and range rate were computed by subtracting the CAS-measured values from the values measured by the tracking radar. A positive error indicates that the CAS measurement was lower than the true value. The errors in CAS measurement of altitude were computed by subtracting the CAS-measured altitude from the altitude that was transmitted as determined from the altitude code of the transmitting aircraft's encoding altimeter. Again, a positive error indicates that the CAS measurement was lower than the true value. The tracking radar measurement of altitude was not used as the true value because its nominal 50-foot error is on the same order of magnitude as the CAS altitude-measurement accuracy. The CAS errors can be summarized as follows:

- The range and range-rate errors are normally distributed.
- The altitude errors are in increments of 100 feet because of the granularity of the encoding altimeters.
- The range and range-rate errors for the FULL CAS systems are statistically independent.
- The range errors for the FULL CAS equipments are slightly affected by the range and range-rate between the aircraft.
- The remaining CAS errors are independent of any test parameters.

The normal distribution was used to compute the probability of various range, range-rate, and altitude errors. The normal distribution is specified by two parameters, the mean and the standard deviation. Table 3-4 showed the mean and standard deviations of the range, range-rate, and altitude errors for the errors observed during the two-aircraft-encounter tests for several combinations of CAS equipments. The mean range error for the FULL CAS equipments is dependent on range and range rate, but it is possible to neglect the variation in mean range error due to range and range rate and still have a good representation of the errors in the FULL CAS.

Table 3-4 distinguishes between a FULL CAS listening to a FULL CAS, a MICRO CAS listening to a FULL CAS, a FULL CAS listening to a MICRO CAS, and a MICRO CAS listening to a MICRO CAS. However, engineering judgment can be exercised to simplify Table 3-4 and obtain the values in Table 6-1 for the mean errors and standard deviations for the FULL CAS and the MICRO CAS, regardless of whether the transmitting equipment is a FULL or MICRO CAS.

Table 6. REPRESENTATIVE CAS STATISTICAL PARAMETERS

Parameter	FULL Systems	MICRO Systems
Mean Range Error	.015 n.mi.	.001 n.mi.
Standard Deviation of Range Error	.035 n.mi.	.057 n.mi.
Mean Range-Rate Error	-20 knots*	
Standard Deviation of Range-Rate Error	40 knots	
Mean Altitude Error	25 feet	20 feet
Standard Deviation of Altitude Error	60 feet	80 feet

* A value of +20 knots should also be considered reasonable.

The Table 6-1 values were not directly derived from Table 3-4, because an allowance was made for two problems that were uncovered during the test program that are not inherent flaws in the overall T/F CAS concept. For the range errors shown, it is assumed that production CAS units would not have the erronous signal-delay compensation that is in the present MICRO CAS. The standard deviations for the altitude errors were adjusted slightly to account for the intermittent operation of the altitude encoding/decoding circuitry of one of the MICRO CAS units tested.

A special analysis of the CAS range data was performed to determine how accurately range rate could be determined from the differences between successive range measurements. This procedure, referred to as "delta range", computes range rate from $(R_2 - R_1)/t$, where R_1 is the range in the first epoch, R_2 is the range in the second epoch, and t is the 3 seconds between epochs. Neglecting data dropout, which could prove to be a problem with this technique, it was found that the resulting range-rate measurement using this method would have essentially a zero mean error. However, the overall root mean square (RMS) error would be about the same as the doppler RMS error. Clearly, the delta-range procedure seemed to be no worse than the doppler technique and would be highly desirable if it were a means of providing a MICRO CAS with the ability to measure range rate.

The T/F CAS error models were used to predict the probability of alarms at various times prior to an encounter. Two of the probability curves presented in Chapter Three are reproduced as Figures 6-1, a and b. These figures indicate (1) the probability that an alarm is given, and (2) the probability that no alarm is given at the specified range or at any of the 3-second points (i.e., at any epoch) prior to the specified range. Appendix F develops a detailed analytical procedure for calculating the range errors for any encounter situation of interest. The altitude errors are also presented in Chapter Three. It was found that the CAS usually will not make more than a 100-foot altitude error and virtually never make a 400-foot altitude error. It should be pointed out that errors are critical to safety only if both CAS's involved in an encounter make errors and, furthermore, continue to make errors for several epochs in a row. On the basis of the nature and magnitude of the observed range, range-rate, and altitude errors, this is highly unlikely.

The CAS warnings and alarms were found to be generated properly for three of the four CAS units, but one unit seemed to be late in displaying warnings and alarms. There is no satisfactory explanation for the operation of this one unit; however, the range and range-rate errors for this unit predict that the warnings and alarms should have been given closer to the nominal times. The warnings and alarms during the traffic-pattern tests were generated as expected. However, the traffic-pattern tests did demonstrate that the errors in measuring range rate could seriously affect operations at closely spaced parallel runways and that dive commands should not be given to aircraft immediately after take-off or just before landing.

6.2 T/F CAS COMMUNICATIONS RELIABILITY

The FULL and MICRO CAS units were observed to communicate reliably at ranges greater than 50 n.mi. during the synchronization and co-slot occupancy tests. However, the ranges of greatest interest, and at which a CAS must operate, are 0 to 15 n.mi., based on a 40-second warning time and up to supersonic closing rates. Therefore, only the two-aircraft-encounter

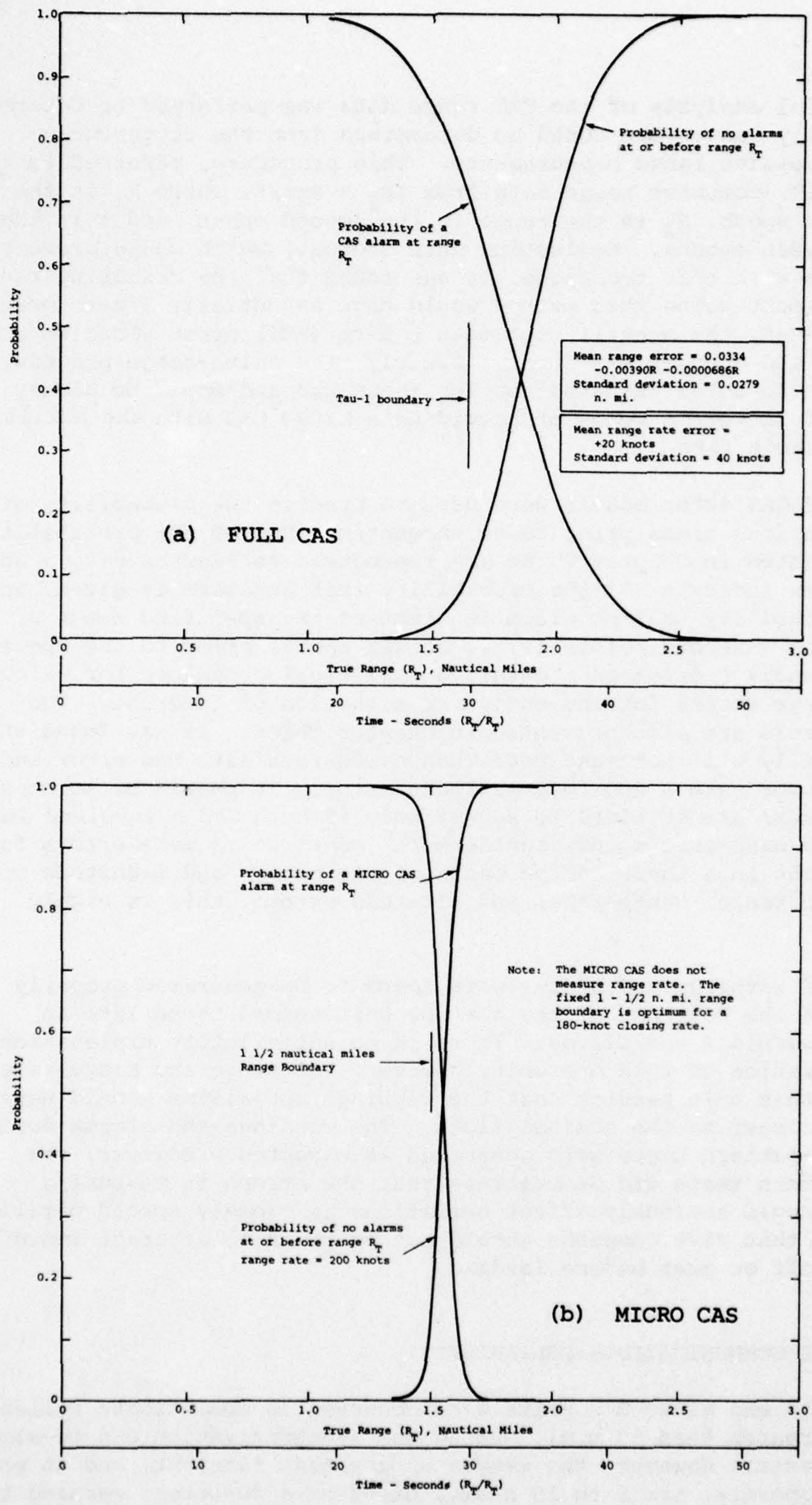


Figure 6-1. **TRUE RANGE VS PROBABILITY OF ALARM AT 200-KNOT RANGE RATE FOR FULL CAS AND MICRO CAS**

data (during which time the aircraft remained within about 15 n.mi. of each other) were analyzed for CAS communications reliability. It was found that the overall probability of one CAS unit hearing and accepting another's transmitted range and altitude pulse was about 97.5 percent. The MICRO CAS typically did slightly better than the FULL CAS because the MICRO CAS does not perform a rigorous examination of range and altitude pulses and does not use a lower antenna. The tests were conducted over water, and it is likely that the multipath interference during reception on the lower antenna was responsible for many of the dropouts by the FULL CAS. The FULL CAS alternately used its top and bottom antennas, and it was found that 90.7% of the signals rejected by the FULL CAS were rejected when it was listening on the bottom antenna.

The MICRO CAS periodically checks for time-slot co-occupants, and these checks have the same effect as a communications dropout. On the average, the MICRO CAS inhibits transmission once in every eight epochs; but the MICRO CAS will not check for co-occupants while a threat is being generated.

The AN/APN-159A radar altimeter was installed in one of the aircraft to determine the extent of its interference on CAS operation. The altimeter was found to have a serious effect on the CAS units on the same aircraft (the FULL CAS accepted only 50% of the signals transmitted to it) and to have a significant effect on the equipments on the other aircraft when they were at a close range.

6.3 T/F CAS SYNCHRONIZATION

The T/F CAS concept requires that the CAS equipments be able to recognize coarse- and fine-synchronization pulse triads to gain and maintain time-base synchronization. One mission was devoted to determining the ability of the MICRO CAS's to detect fine- and coarse-synchronization triads. The MICRO CAS was examined in this manner because it is likely to be more susceptible to synchronization problems than the FULL CAS. It was found that the MICRO CAS had little trouble obtaining fine-synchronization triads because multiple triads generally appeared to be a single triad. The fine-synchronization triads are transmitted so as to arrive at the recipient at precisely the same time and should, therefore, be overlapped and appear as one triad. The coarse-synchronization triads are transmitted at the beginning of an epoch and may arrive at the recipient at random times, depending on the actual range between aircraft. The MICRO CAS would only recognize clean epoch-start triads and would reject interleaved triads. Therefore, the MICRO CAS will occassionally have trouble recognizing a coarse-synchronization triad in a dense aircraft environment. However, coarse-synchronization triads transmitted by a ground station should be received clearly and properly if the aircraft is within 49 n.mi. and within line-of-site of the ground station. Failures to recognize coarse-synchronization triads will result in a delay of the initial acquisition of fine synchronization. Once fine synchronization is achieved, the CAS will ignore coarse-synchronization triads.

A second phase of the synchronization tests determined that a MICRO CAS would have little trouble obtaining synchronization from a commercial aircraft at cruise altitudes and at ranges out to at least 50 n.mi.

6.4 THREE-AIRCRAFT ENCOUNTERS

A series of three-aircraft encounters involving aircraft equipped with MICRO CAS and FULL CAS were conducted to demonstrate the problems that could arise in three-aircraft encounters with systems having different threat logic. These tests demonstrated that a FULL CAS-equipped aircraft flying at an altitude that is between two MICRO CAS-equipped aircraft (or one MICRO and one FULL) would be restricted in its ability to maneuver until the MICRO CAS generated a maneuver command. The MICRO CAS could be late in generating the escape-maneuver command because of the fixed alarm-range boundaries. However, the middle aircraft would be allowed to maneuver slightly in the vertical plane as long as the aircraft above or below were at least 700 feet above or below it.

6.5 SUPERSONIC ENCOUNTERS

The supersonic encounters demonstrated that the CAS equipments will operate at supersonic speeds, but that they are susceptible to interference from other on-board equipments such as the rotating beacon or Grimes light. The on-board interference experienced during the F-106 test flights prevented reliable communications at ranges greater than 15 n.mi. Other tests with other aircraft demonstrated that the CAS equipments have sufficient transmitter power and receiver sensitivity to communicate reliably at ranges over 50 n.mi.; hence, it was concluded that the communications problems were peculiar to the installations in the F106 aircraft.

6.6 BACK-UP-MODE TEST

The T/F CAS concept includes a back-up mode for FULL CAS equipments that are unable to obtain time-base synchronization. These tests demonstrated that the CAS equipments can measure range rate and altitude separation with sufficient accuracy while in the back-up mode to provide the back-up mode collision-avoidance protection.

6.7 RESOLUTION OF T/F CAS TIME-SLOT CO-OCCUPANCY CONFLICT

The ability of the CAS equipments to detect and resolve time-slot co-occupancy problems was studied during both the flight tests and the laboratory tests. The following results were determined:

- If there are as many free time slots as there are systems, each CAS equipment will find a free time slot. (This should be qualified slightly because the MICRO CAS's can transmit on only one frequency, chosen randomly at the time of manufacture, and a time slot on that one frequency must be available.)

- In a mixed environment of MICRO CAS's and FULL CAS's, in which there are fewer available time slots than there are systems, the FULL CAS will always find a time slot.

- If all time slots are filled, the FULL CAS will not check for time-slot co-occupants.

- If all other slots are filled and two MICRO CAS's are contending for the same time slot, they will take turns occupying it as each checks for a co-occupant.

- The CAS equipments will not check for time-slot co-occupants if the CAS is generating a threat.

The foregoing results were determined in the laboratory. However, the flight tests did illustrate an additional aspect of the time-slot co-occupancy problem. If the FULL CAS can hear a system on only one of its two antennas, it will not detect a time-slot co-occupant if the check is made with the wrong antenna. This problem should have little practical impact because, when the aircraft are close enough to be a mutual threat, they should be able to hear each other with either the top or the bottom antenna.

6.8 T/F CAS SUSCEPTIBILITY TO INTERFERENCE

Interference from the AN/APN-159A radar altimeter on the T/F CAS equipments was anticipated, and flight tests were planned to evaluate this interference. The AN/APN-155B radar altimeter and the Grimes light were also found to affect the T/F CAS equipments during the flight-test program. All three types of interference were further investigated in the laboratory.

The AN/APN-159A caused the FULL CAS and, to a lesser extent, the MICRO CAS to reject otherwise valid T/F CAS signals. The AN/APN-159A did not generate erroneous range, range-rate, or altitude readings in the CAS equipments.

The AN/APN-155B has a lower power output and, when operated on transient F-4 aircraft, it affected only the ground station during the flight-test program. In the laboratory the AN/APN-155B was found to be able to deny completely the highest CAS frequency (1615 MHz) to both the FULL and MICRO CAS equipments by making it appear that all 500 time slots on that frequency were occupied. The altimeter had no effect on the other three CAS frequencies, and it had no other effect on the FULL CAS. However, it did cause the MICRO CAS to generate false alarms in the laboratory.

A Grimes light was operated in the laboratory near the antenna of a FULL CAS unit, and the CAS was found to decode false coarse-synchronization signals from the RF energy generated by the light. The Grimes-light interference would not prevent a FULL CAS from receiving a coarse synchronization but could delay the receipt of coarse synchronization by many epochs, as was demonstrated by the FULL CAS units on the F-106 aircraft.

6.9 CAS OSCILLATOR STABILITY

The T/F CAS oscillator must be of high quality to permit the T/F CAS equipments to operate properly. A stability or frequency offset of 2 parts in 10^8 is required, and laboratory tests were performed to determine the actual stability of the CAS oscillators.

The FULL CAS oscillator appeared to have a stability on the order of 1 part in 10^9. This is much better than the 1 part in 10^8 assumed in the design of the FULL CAS hierarchy-demotion circuitry. While it is probably better to err on the conservative side, it would appear that the FULL CAS oscillators are underutilized.

The MICRO CAS oscillator stability appears just to meet the stability requirement of 2 parts in 10^8. It is believed that a slight improvement in MICRO CAS oscillator stability would be desirable and could be obtained by enclosing the oscillator in a temperature-stabilizing blanket or oven.

6.10 EFFECT OF HELICOPTER ROTOR BLADES

The effect of helicopter rotor blades was evaluated in the laboratory, and it was found that they created no apparent problems.

CHAPTER SEVEN

CONCLUSIONS AND RECOMMENDATIONS

7.1 CONCLUSIONS

The time/frequency technique for detecting and avoiding threatening aircraft is capable of providing the collision-avoidance function accurately and reliably. This conclusion is based on the performance of the equipments tested in the areas of capability on which the successful performance of T/F CAS depends. These areas are discussed in the following subsections.

7.1.1 Measurement of Threat-Evaluation Parameters

The full systems tested measured range, range rate, and altitude separation with the accuracy required to evaluate threats correctly and to generate the proper warnings and maneuver commands within time margins that permit avoidance to be accomplished with the allowable 1/4 g. escape maneuvers. The MICRO CAS equipments tested measured range and altitude separation accurately, but the lack of a range-rate measurement capability adversely affected the timeliness of generation of warnings and maneuver commands.

7.1.2 Communications Reliability

The exchange of accurate information between the systems was sufficiently reliable (e.g., about 97%) to provide a low probability of a missed or false alarm on any communication. The use of upper and lower antennas by full systems adversely affected communications reliability of the full systems because the greater strength of multipath signals arriving at the lower antenna increased the rate of signal rejection. However, the degradation was not great enough to reduce the communications reliability below 90%.

7.1.3 Time and Frequency Synchronization

The fine-synchronization process was accomplished with very high reliability. The process is also extremely accurate, as reflected by the accuracy of range measurement.

7.1.4 Tolerance to Large Numbers of Aircraft

The system can accommodate aircraft in numbers up to the total number of time slots available for aircraft use (1938 slots). The system will not saturate until this number of aircraft are brought together within mutual communications range (about 100 n. mi.).

7.1.5 Susceptibility to Interference

The T/F CAS is susceptible to interference. For the full system, the only effect of interference is a reduction in communications reliability. For the MICRO CAS, interference reduces communications reliability and can also cause the generation of false alarms.

7.2 RECOMMENDATIONS

Operating characteristics observed during the testing indicated that some modifications should be made in the T/F CAS equipments and concept:

- The stability of the reference oscillator installed in the FULL CAS should be more fully exploited. The stability demonstrated by these oscillators will permit the extension of the hierarchy run-down period to at least 45 minutes instead of the present four minutes. This change would aid the process of propagating synchronized operation into areas remote from ground stations as long as the same oscillators were used in production units.

- The MICRO CAS should have a more stable oscillator. Installing the present oscillator in a simple oven to provide a more stable temperature environment would probably provide the desired improvement with an inconsequential increase in cost.

- The MICRO CAS should have more selective criteria for acceptance of range and altitude pulses. The modification would eliminate the generation of false alarms from electromagnetic interference. By FCC rules, the CAS frequency band should be free of interference from out-of-band-equipments; however, it is believed that the MICRO CAS is too susceptible to such interference, which could be generated by out-of-band equipments that are operating improperly.

- All T/F CAS equipment designs should have an acceptance gate for fine-synchronization replies to prevent capture should a synchronization donor ever become time-misaligned.

- All equipment designs permitted by the concept should provide collision protection for own aircraft and should provide for measurement of range rate as a parameter in the determination of the horizontal boundary of the protection envelope. The small, but finite, possibility of maneuver constraints being imposed by the presence of a third aircraft make it undesirable for any airborne collision-avoidance equipments to have fixed boundaries on the protection envelope or be incapable of generating warnings and maneuver commands for the protection of own aircraft.

- Because of susceptibility of multipath interference, the use of a lower antenna for transmission and reception of T/F CAS signals is questionable.

APPENDIX A

DESCRIPTION OF T/F CAS CONCEPT AND HARDWARE

This appendix describes the major characteristics of the T/F CAS concept and hardware. A detailed description is contained in ARINC Characteristic No. 587, "Air Transport Time-Frequency Collision Avoidance System".

GENERAL

The time/frequency collision avoidance system (T/F CAS) is a co-operative system designed to provide equipped aircraft with sufficient data to detect, and escape from, a threat of collision with any other similarly equipped aircraft. The appropriate advisory information and avoidance-maneuver command with respect to the threat are displayed in the flight deck. The principle of operation is time-division multiplex based on precise time synchronization of all systems and time-controlled frequency switching, which allows for the interchange of data between 2000 systems. There are 2000 time slots available, but 64 of them are reserved for first-slot identification, ground stations, terrain/obstacle-avoidance equipments, and self test; therefore, there are 1936 time slots available for use by airborne equipment.

Each T/F CAS equipment contains a crystal oscillator with a stability of one part in 10^8 or better for full systems, or two parts in 10^8 or better for limited systems. Provision is also made in full systems for using an atomic oscillator with a stability of one part in 10^{11}. The time reference provided by the oscillator is used to establish frequency switching and the transmission schedule of the system. Each system is precisely time-synchronized with all other systems by a synchronization technique such that all systems are frequency-switching in unison and transmitting in their own time slots with a timing error as low as 0.25 microsecond and no larger than two microseconds.

The T/F CAS employs a three-second cycle, referred to as an epoch, which is divided into 2000 time slots, or message slots, each 1500 microseconds long (see Figure A-1). Successive time slots are separated by cyclically switching the operating frequency among four discrete frequencies as shown in Figure A-2. Each operating CAS equipment selects one of these time slots as the one in which it will transmit its message. During that time

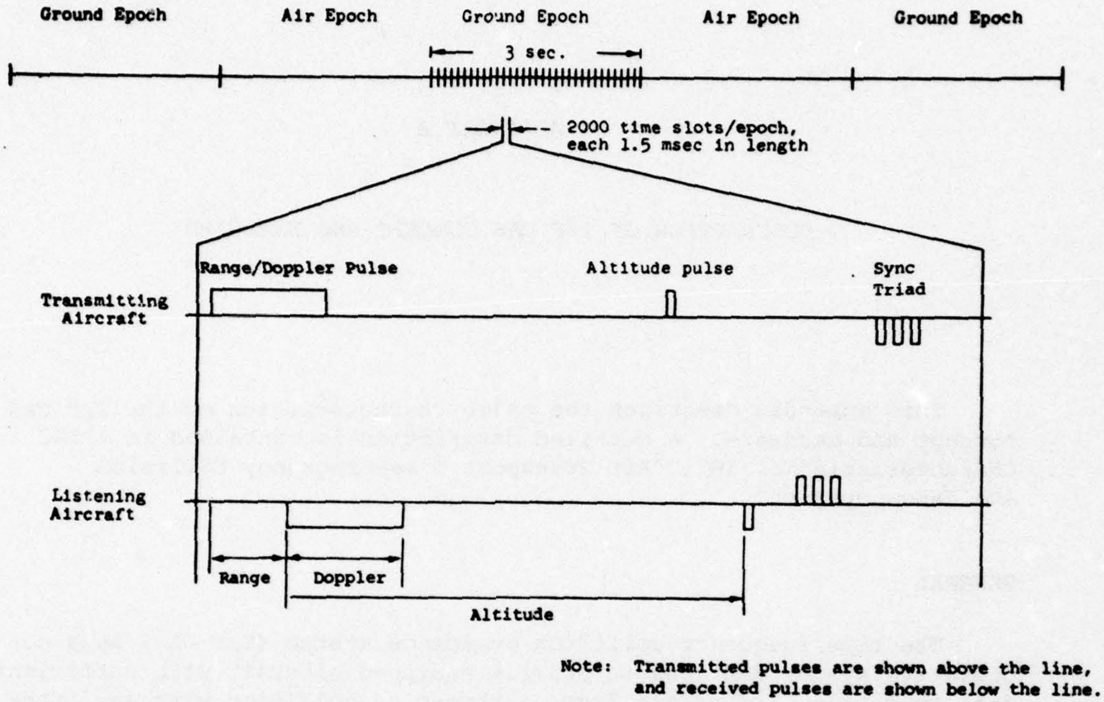


Figure A-1. **T/F CAS TIMING**

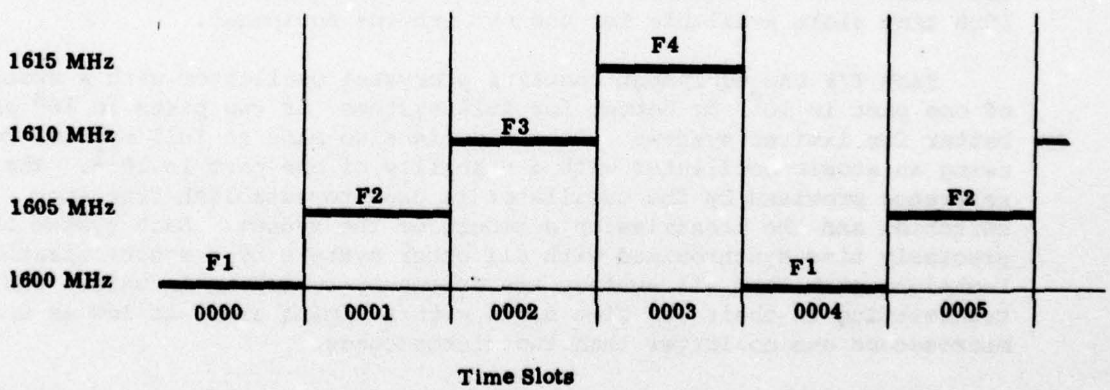


Figure A-2. **T/F CAS FREQUENCIES**

slot all other systems within communication range will receive the message and will evaluate the data for a collision threat. The T/F CAS message format, Figure A-3., consists of a 200-microsecond range pulse transmitted 15 microseconds after the start of the slot and a 25.6 microsecond altitude pulse time-coded with respect to the leading edge of the range pulse. Supplementary data are transmitted by full systems by means of biphase modulation of the middle 120 microseconds of the range pulse. The biphase modulation consists of an even number of phase reversals of the carrier in order to minimize adverse effects on doppler measurements, and it is coded to produce the desired binary message. There are 120 bits available for transmission of biphase data; 40 bits have been assigned as shown in Figure A-3, and 80 bits are available for future expansion.

PARAMETER MEASUREMENT FROM THE RECEIVED MESSAGE

The parameters that are measured to provide the input data for threat evaluation are range, range rate, and altitude. The range to the transmitting aircraft is determined by measuring the delay from the known time of transmission (t_o) to the time of arrival of the leading edge of the range pulse. The range rate is determined by measuring the doppler shift of the carrier frequency of the received range pulse by comparing the received frequency with the frequency of the receiver's reference oscillator. The altitude of the transmitting aircraft is determined by measuring the elapsed time between arrival of the leading edge of the range pulse and arrival of the leading edge of the altitude pulse. The transmitting aircraft time-codes its altitude pulse as a function of the altitude code obtained from a digital encoding barometric altimeter. The time coding of the altitude pulse is shown in Figure A-3 Each aircraft that receives the CAS message decodes the altitude received and compares it with its own encoding-altimeter output to determine the altitude difference between it and the transmitting aircraft.

THREAT LOGIC

The T/F CAS protection-envelope boundaries consist of altitude differences in the vertical direction and time to collision (Tau) in the horizontal direction. The protection envelope is depicted in Figure A-4. In the vertical the envelope is divided into three zones: the co-altitude zone, aircraft above zone, and aircraft below zone. In the horizontal the envelope is divided into two zones: the Tau 2 zone and the Tau 1 zone. If an aircraft is sensed to be within the protection envelope, there will be a display on the CAS indicator. If the aircraft is inside the Tau 1 zone and the co-altitude zone, the indicator will display a maneuver command. If the aircraft is in any other part of the protection envelope, the indicator will display one of the advisories as shown in the figure. The figure also shows that if the aircraft is climbing or descending, the co-altitude boundary is extended in the direction of movement by an amount equal to one-half the altitude rate; e.g., if the aircraft is climbing at 1000 feet per minute, the upper altitude boundary becomes 1300 feet (800 + (1000) 1/2).

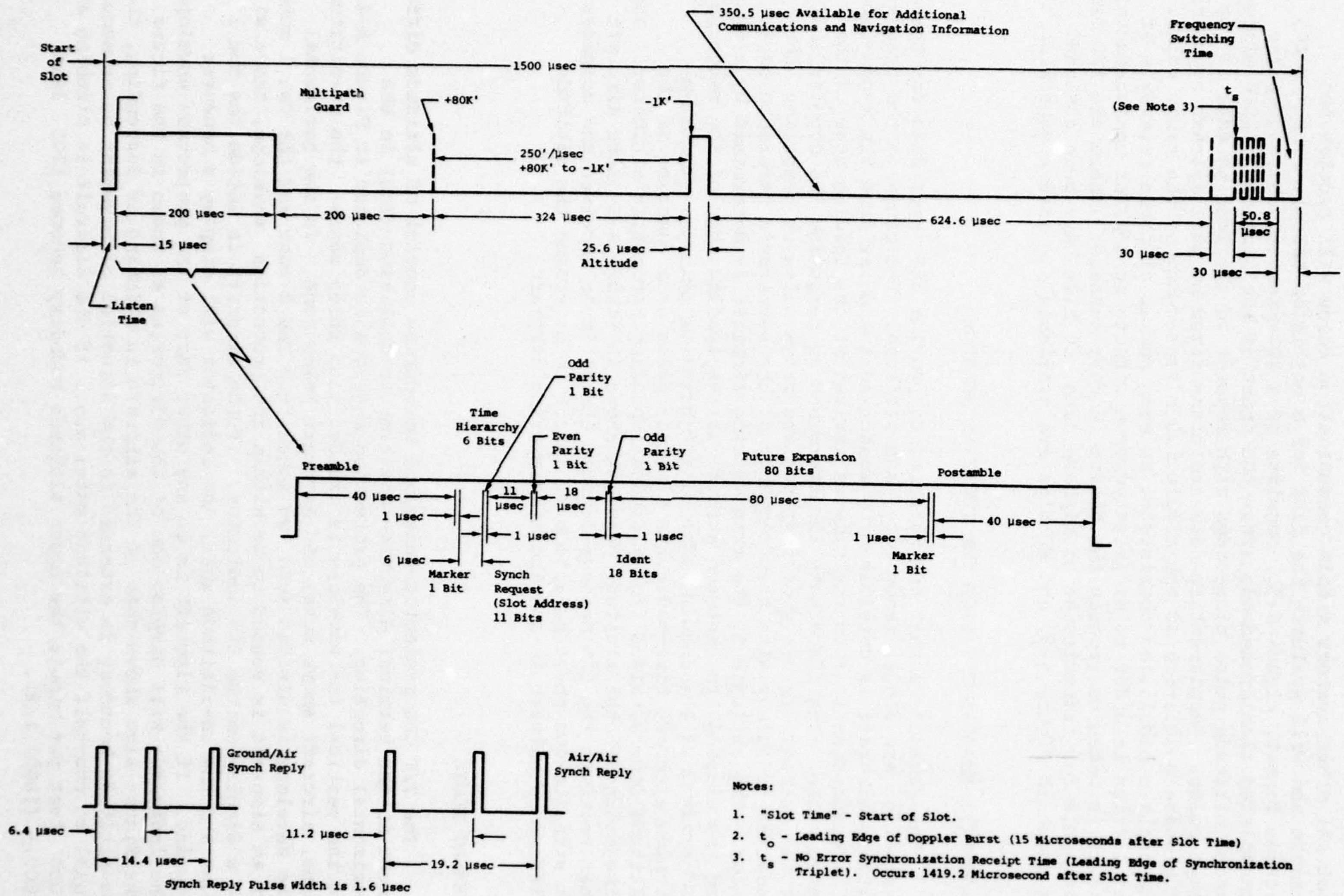


Figure A-3. **CAS MESSAGE FORMAT**

Notes:

1. "Slot Time" - Start of Slot.
2. t_o - Leading Edge of Doppler Burst (15 Microseconds after Slot Time)
3. t_s - No Error Synchronization Receipt Time (Leading Edge of Synchronization Triplet). Occurs 1419.2 Microsecond after Slot Time.

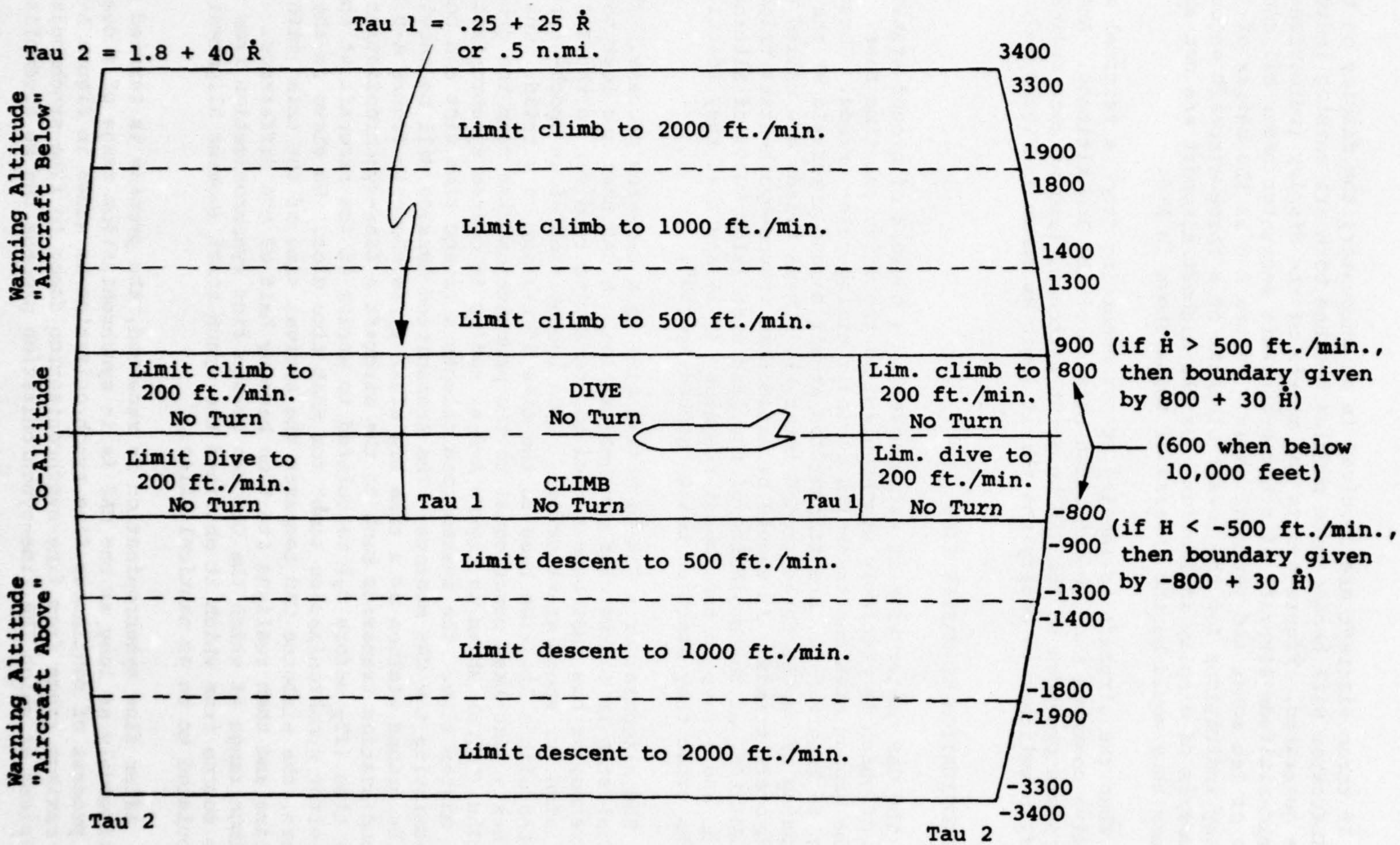


Figure A-4. SCHEMATIC REPRESENTATION OF THE HIGH-ALTITUDE THREAT ZONES DEFINED BY ANTC 117

If three aircraft are involved in an encounter, the display on the CAS indicator will become more complex because both are causing indications to be generated. Figure A-5 is the matrix of the display indications for the mid-altitude aircraft of a three-aircraft encounter under all conditions of Tau zones and vertical rates. Figure A-6 is the matrix of the display indications for the lowest aircraft of a three-aircraft encounter. The matrix of display indications for the highest aircraft are not shown because they would be the inverse of those shown in A-6.

When the aircraft is landing at or departing from a terminal area, the dive commands must be inhibited because of the low altitude. Automatic inputs are provided to the CAS by strut switches, landing-gear switches, and flap switches to modify the threat logic as shown in Figure A-7.

SYNCHRONIZATION TO MASTER TIME

The CAS master time is established by a network of ground stations, each of which is precisely synchronized to the universal time base. Each of the ground stations transmits periodic timing-pulse triads. These triads, shown in Figure A-8., are transmitted at six-second intervals at the beginning of a CAS three-second interval. These triads are called ground-epoch-start triads. It should be noted that ground-epoch-start triads are transmitted at the beginning of the lead slot (slot 0000) of alternate epochs and always on the lowest frequency (F-1) and that they identify the epochs that they start as being "ground epochs".

The alignment of a CAS to master time is a two-step process. The initial step is coarse time synchronization. A CAS that has lost the time reference, or has just been turned on, tunes its receiver to the F-1 frequency to listen for epoch-start triads. Upon recognition of an epoch-start triad, the CAS aligns its time base to the time of receipt of a triad. The CAS now has a time-base error equal to the propagation time from the ground station (T_R), as shown in Figure A-9.a, and is in coarse synchronization with master time. The system then selects a vacant time slot and begins transmitting the CAS message. The transmitted message will be received at the ground station at a time $2T_R$ after t_o, as shown in Figure A-9.b. The ground station transmits back to the aircraft a fine-synchronization triad at a time ($2T_R$ before t_s) calculated to arrive at the aircraft at the "no-error synchronization time" for that time slot. As shown in the figure, the airborne CAS compares the arrival time of the triad with its t_s time and then realigns its time base by half of the difference. The maximum range at which the CAS can obtain fine synchronization from the same source from which it obtained the epoch start (coarse alignment) is calculated to be 49 nautical miles.

After fine synchronization is received, the process is carried on continuously as long as the CAS is in synchronization range of a donor. The process of continuous fine synchronization is shown in Figure A-9.c. The maximum range from fine-synchronization donor to fine-synchronization recipient at which the fine-synchronization process can be accomplished

Intruder Below / Intruder Above (THREAT STATUS)	Coaltitude Tau 1	Coaltitude Tau 2	Predicted Coaltitude $\Delta h \le 1300$ ft Tau 2	$\Delta h \le 1300$ ft Tau 2	Predicted Coaltitude $\Delta h \le 1800$ ft Tau 2	$\Delta h \le 1800$ ft Tau 2	Predicted Coaltitude $\Delta h \le 3300$ ft Tau 2	$\Delta h \le 3300$ ft Tau 2
$\Delta h \le 3300$ ft Tau 2	Dive Do Not Turn LVS 0 fpm Up 2000 fpm Down	Do Not Turn LVS 200 fpm Up 2000 fpm Down	Level Off Do Not Turn LVS 500 fpm Up 2000 fpm Down	LVS 500 fpm up 2000 fpm Down	Level Off Do Not Turn LVS 1000 fpm Up 2000 fpm Down	LVS 1000 fpm Up 2000 fpm Down	Level Off Do Not Turn LVS 2000 fpm Up 2000 fpm Down	LVS 2000 fpm Up 2000 fpm Down
Predicted Coaltitude $\Delta h \le 3300$ ft Tau 2	Level Off Do Not Turn LVS 500 fpm Up 2000 fpm Down	Level Off Do Not Turn LVS 1200 fpm Up 2000 fpm Down	N/A	Level Off Do Not Turn LVS 500 fpm Up 2000 fpm Down	N/A	Level Off Do Not Turn LVS 1000 fpm Up 2000 fpm Down	N/A	Level Off Do Not Turn LVS 2000 fpm Up 2000 fpm Down
$\Delta h \le 1800$ ft Tau 2	Dive Do Not Turn LVS 0 fpm Up 1000 fpm Down	Do Not Turn LVS 200 fpm Up 1000 fpm Down	Level Off Do Not Turn LVS 500 fpm Up 1000 fpm Down	LVS 500 fpm Up 1000 fpm Down	Level Off Do Not Turn LVS 1000 fpm Up 1000 fpm Down	LVS 1000 fpm Up 1000 fpm Down	Level Off Do Not Turn LVS 2000 fpm Up 1000 fpm Down	LVS 2000 fpm Up 1000 fpm Down
Predicted Coaltitude $\Delta h \le 1800$ ft Tau 2	Level Off Do Not Turn LVS 500 fpm Up 1000 fpm Down	Level Off Do Not Turn LVS 200 fpm Up 1000 fpm Down	N/A	Level Off Do Not Turn LVS 500 fpm Up 1000 fpm Down	N/A	Level Off Do Not Turn LVS 1000 fpm Up 1000 fpm Down	N/A	Level Off Do Not Turn LVS 2000 fpm Up 1000 fpm Down
$\Delta h \le 1300$ ft Tau 2	Dive Do Not Turn LVS 0 fpm Up 500 fpm Down	Do Not Turn LVS 200 fpm Up 500 fpm Down	Level Off Do Not Turn LVS 500 fpm Up 500 fpm Down	LVS 500 fpm Up 500 fpm Down	Level Off Do Not Turn LVS 1000 fpm Up 500 fpm Down	LVS 1000 fpm Up 500 fpm Down	Level Off Do Not Turn LVS 2000 fpm Up 500 fpm Down	LVS 2000 fpm Up 500 fpm Down
Predicted Coaltitude $\Delta h \le 1300$ ft Tau 2	Level Off Do Not Turn LVS 500 fpm Up 500 fpm Down	Level Off Do Not Turn LVS 200 fpm Up 500 fpm Down	N/A	Level Off Do Not Turn LVS 500 fpm Up 500 fpm Down	N/A	Level Off Do Not Turn LVS 1000 fpm Up 500 fpm Down	N/A	Level Off Do Not Turn LVS 2000 fpm Up 500 fpm Down
Coaltitude Tau 2	Dive Do Not Turn LVS 0 fpm Up 2000 fpm Down	Do Not Turn LVS 200 fpm Up 200 fpm Down	Level Off Do Not Turn LVS 500 fpm Up 200 fpm Down	Do Not Turn LVS 500 fpm Up 200 fpm Down	Level Off Do Not Turn LVS 1000 fpm Up 200 fpm Down	Do Not Turn LVS 1000 fpm Up 200 fpm Down	Level Off Do Not Turn LVS 2000 fpm Up 200 fpm Down	Do Not Turn LVS 2000 fpm Up 200 fpm Down
Coaltitude Tau 1	Hold Altitude Do Not Turn LVS 0 fpm Up 0 fpm Down	Climb Do Not Turn LVS 200 fpm Up 0 fpm Down	Level Off Do Not Turn LVS 500 fpm Up 500 fpm Down	Climb Do Not Turn LVS 500 fpm Up 0 fpm Down	Level Off Do Not Turn LVS 1000 fpm Up 500 fpm Down	Climb Do Not Turn LVS 1000 fpm Up 0 fpm Down	Level Off Do Not Turn LVS 2000 fpm Up 500 fpm Down	Climb Do Not Turn LVS 2000 fpm Up 0 fpm Down

NOTE: LVS = "Limit Vertical Speed" to values listed.

Figure A-5. **THREE-AIRCRAFT-ENCOUNTER THREAT LOGIC OUTPUT -- INTRUDERS ABOVE AND BELOW**

Intruder Above (rows) / Intruder Above (columns) / THREAT STATUS	Coaltitude Tau 1	Coaltitude Tau 2	Predicted Coaltitude $\Delta h \leq 1300$ ft Tau 2	$\Delta h \leq 1300$ ft Tau 2	Predicted Coaltitude $\Delta h \leq 1800$ ft Tau 2	$\Delta h \leq 1800$ ft Tau 2	Predicted Coaltitude $\Delta h \leq 3300$ ft Tau 2	$\Delta h \leq 3300$ ft Tau 2
$\Delta h \leq 3300$ ft Tau 2	Dive Do Not Turn LVS 0 fpm Up	Do Not Turn LVS 200 fpm Up	Level Off Do Not Turn LVS 500 fpm Up	LVS 500 fpm Up	Level Off Do Not Turn LVS 1000 fpm Up	LVS 1000 fpm Up	Level Off Do Not Turn LVS 1000 fpm Up	LVS 2000 fpm Up
Predicted Coaltitude $\Delta h \leq 3300$ ft Tau 2	Level Off Do Not Turn LVS 500 fpm Up	Level Off Do Not Turn LVS 200 fpm Up	Level Off Do Not Turn LVS 500 fpm Up	N/A	Level Off Do Not Turn LVS 1000 fpm Up	N/A	Level Off Do Not Turn LVS 2000 fpm Up	Level Off Do Not Turn LVS 2000 fpm Up
$\Delta h \leq 1800$ ft Tau 2	Dive Do Not Turn LVS 0 fpm Up	Do Not Turn LVS 200 fpm Up	Level Off Do Not Turn LVS 500 fpm Up	LVS 500 fpm Up	Level Off Do Not Turn LVS 1000 fpm Up	LVS 1000 fpm Up	N/A	LVS 1000 fpm Up
Predicted Coaltitude $\Delta h \leq 1800$ ft Tau 2	Level Off Do Not Turn LVS 500 fpm Up	Level Off Do Not Turn LVS 200 fpm Up	Level Off Do Not Turn LVS 500 fpm Up	N/A	Level Off Do Not Turn LVS 1000 fpm Up	Level Off Do Not Turn LVS 1000 fpm Up	Level Off Do Not Turn LVS 1000 fpm Up	Level Off Do Not Turn LVS 1000 fpm Up
$\Delta h \leq 1300$ ft Tau 2	Dive Do Not Turn LVS 0 fpm Up	Do Not Turn LVS 200 fpm Up	Level Off Do Not Turn LVS 500 fpm Up	LVS 500 fpm Up	N/A	LVS 500 fpm Up	N/A	LVS 500 fpm Up
Predicted Coaltitude $\Delta h \leq 1300$ ft Tau 2	Level Off Do Not Turn LVS 500 fpm Up	Level Off Do Not Turn LVS 200 fpm Up	Level Off Do Not Turn LVS 500 fpm Up	Level Off Do Not Turn LVS 500 fpm Up	Level Off Do Not Turn LVS 500 fpm Up	Level Off Do Not Turn LVS 500 fpm Up	Level Off Do Not Turn LVS 500 fpm Up	Level Off Do Not Turn LVS 500 fpm Up
Coaltitude Tau 2	Dive Do Not Turn LVS 0 fpm Up	Do Not Turn LVS 200 fpm Up	Do Not Turn LVS 200 fpm Up	Do Not Turn LVS 200 fpm Up	Do Not Turn LVS 200 fpm Up	Do Not Turn LVS 200 fpm Up	Do Not Turn LVS 200 fpm Up	Do Not Turn LVS 200 fpm Up
Coaltitude Tau 1	Dive Do Not Turn LVS 0 fpm Up	Dive Do Not Turn LVS 0 fpm Up	Level Off Do Not Turn LVS 500 fpm Up	Dive Do Not Turn LVS 0 fmp Up	Level Off Do Not Turn LVS 500 fpm Up	Dive Do Not Turn LVS 500 fpm Up	Level Off Do Not Turn LVS 500 fpm Up	Dive Do Not Turn LVS 0 fpm Up

NOTE: LVS = "Limit Vertical Speed" to values listed.

Figure A-6. THREE-AIRCRAFT-THREAT LOGIC OUTPUT -- BOTH INTRUDERS ABOVE

Aircraft Operation	Inputs	Transmit		Threat Logic		
		Range	Altitude	Synchronized Mode		Back-Up Mode
				Process Receptions	Logic (1)	Participation
On Ground	Oleo Strut Switch (2)	Yes	No	No	---	Inhibit
Takeoff						
0 thru 12-15 sec. (3)	"	Yes	No	No	---	Inhibit
12-16 thru 45-48 sec. (3)	"	Yes	Yes	Yes	Inhibit; "Dive" and "Do Not Turn" commands and Tau 2	Inhibit
Climb Out, Cruise and Let Down		Yes	Yes	Yes	Full	Normal
Landing	Landing Gear (4) Down & Locked	Yes	Yes	Yes	Inhibit; "Dive" and "Do Not Turn" commands and Tau 2	Inhibit

(1) Altitude band values depend on aircraft altitude.

(2) Also referred to as "Air/Ground" circuit.

(3) Relative to time of takeoff. Time out is done within CAS.

(4) On some airplanes, where the landing gear is occasionally used as a speed brake, this input may need to be combined with "landing flaps down".

Figure A-7. CAS THREAT-LOGIC AUTOMATIC OPERATION CONTROLS

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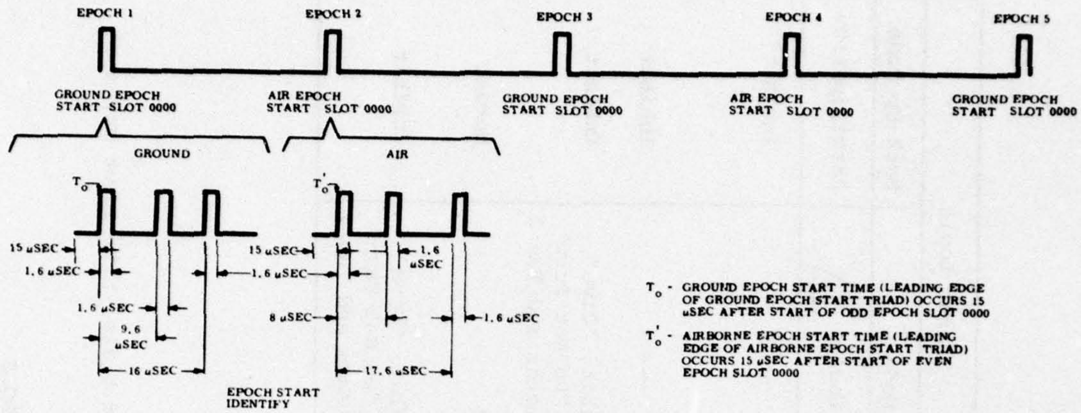


Figure A-8. GROUND/AIR EPOCH-START TRIADS

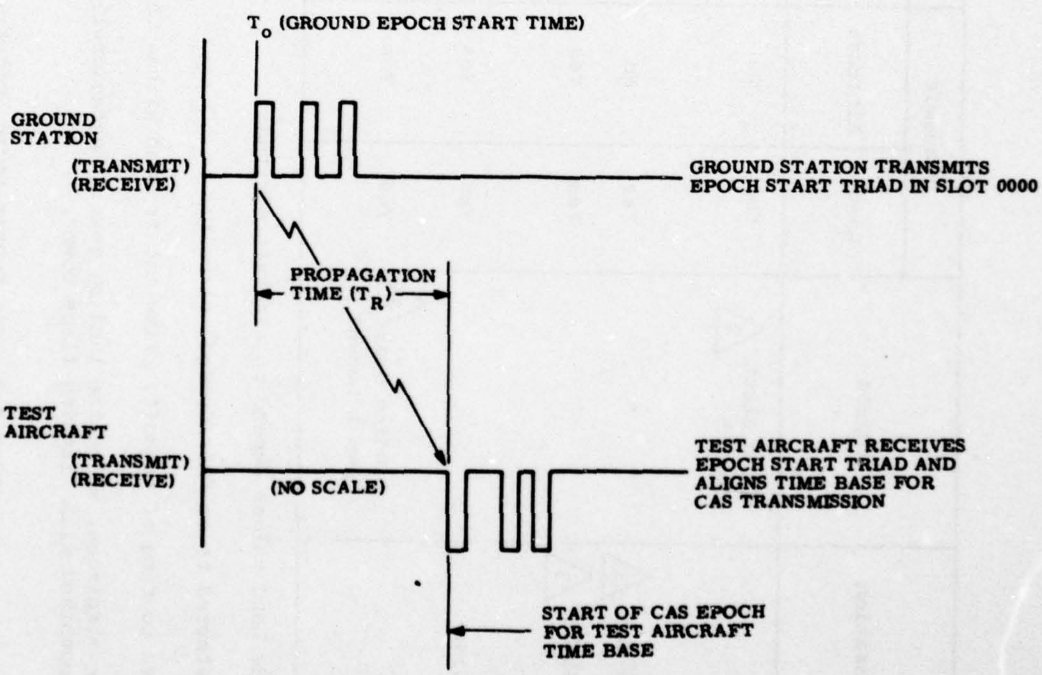


Figure A-9a. COARSE SYNCHRONIZATION

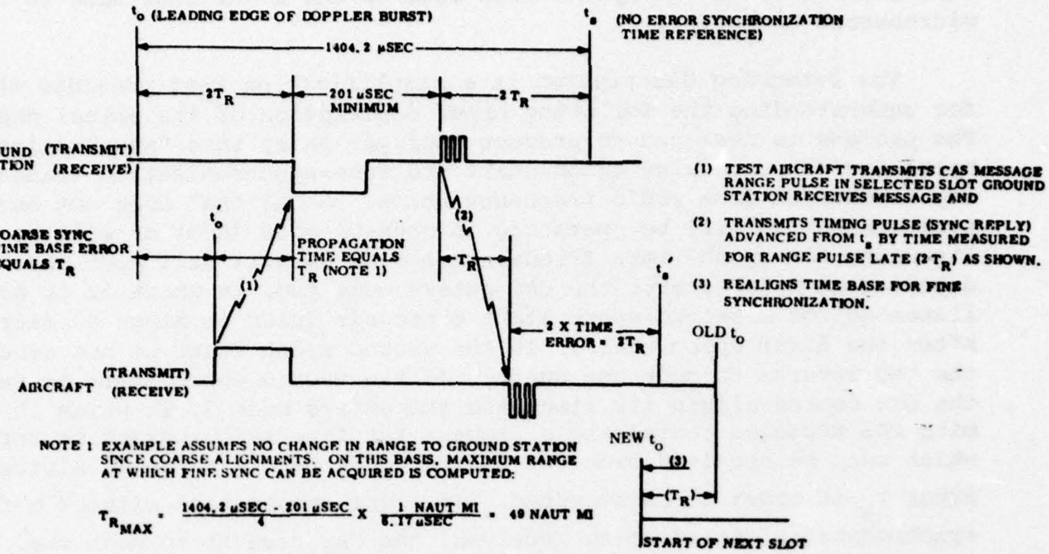


Figure A-9b. INITIAL FINE SYNCHRONIZATION

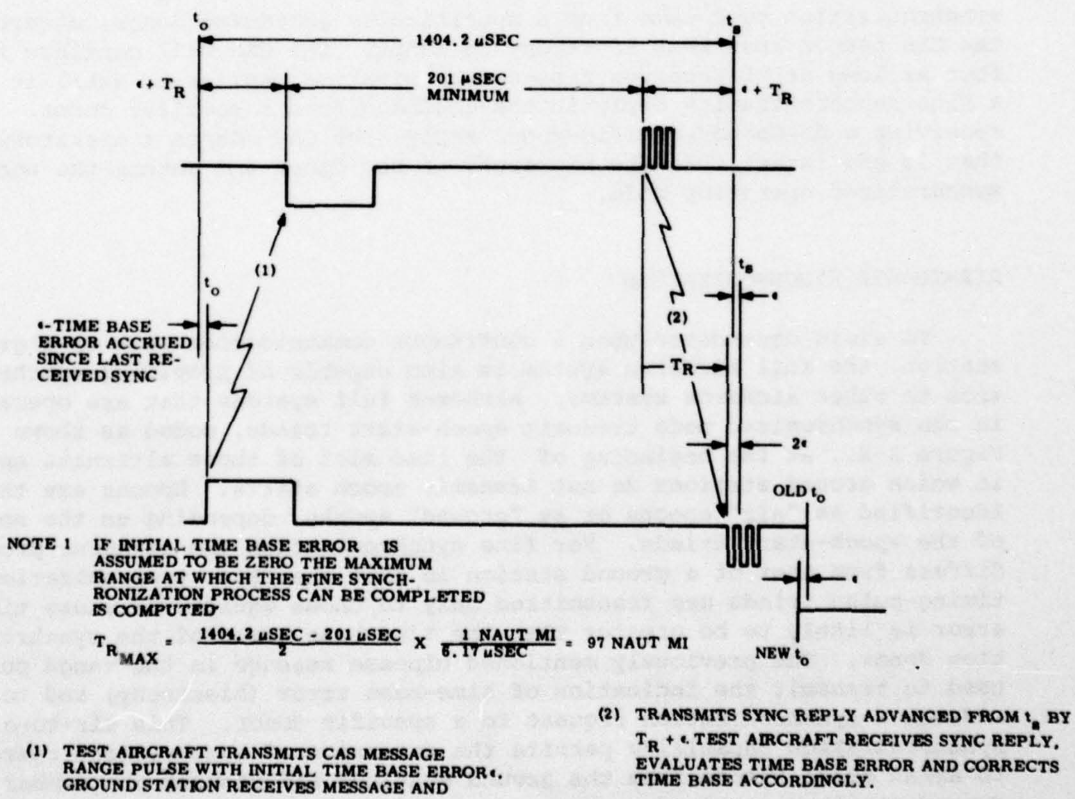


Figure A-9c. CONTINUOUS FINE SYNCHRONIZATION

is calculated to be 97 nautical miles. The process accomplishes synchronization of the recipient time base to the donor time base to 0.25 microsecond or better.

The foregoing description is a simplification that provides the basis for understanding the following brief description of the actual process. The process is designed to prevent improper entry into "synchronized" operation through false epoch-start and fine-synchronization triads that may be decoded from radio frequency noise. A CAS that does not have time synchronization will be operating in back-up mode (BUM) or will be simply listening for epoch-start triads; this mode we will call mode one. Upon decoding an epoch start, the CAS enters mode two, in which it is now listening for a second epoch start 6 seconds (plus or minus 40 microseconds) after the first epoch start. If the second epoch start is not received, the CAS reverts to mode one again. If the second epoch start is received, the CAS coarse-aligns its time base and enters mode 3, in which it transmits CAS messages containing a request for fine-synchronization replies, which must be received from 600 microseconds before t_s to 20 microseconds after t_s in order to be accepted. If eight epochs pass without a fine-synchronization triad being received, the CAS reverts to mode one. If a fine-synchronization triad is received, the CAS realigns its time base and reduces its fine-synchronization window to ±20 microseconds of t_s and enters mode four. In mode four the CAS is looking for a fine-synchronization triad to arrive within a two-microsecond deadband centered on t_s. This fine synchronization must come from a specifically addressed donor; otherwise, the CAS cannot know what hierarchy to adopt. The CAS will continue in mode four as long as it receives fine-synchronization replies or until it receives a fine-synchronization reply in the deadband from a specific donor. Upon receiving a deadband/specific-donor reply, the CAS adopts a hierarchy number that is one larger than the hierarchy of the donor and enters the normal synchronized operating mode.

AIR-TO-AIR SYNCHRONIZATION

To avoid dependence upon a continuous communication path to a ground station, the full airborne system is also capable of providing synchronization to other airborne systems. Airborne full systems that are operating in the synchronized mode transmit epoch-start triads, coded as shown in Figure A-8., at the beginning of the lead slot of those alternate epochs in which ground stations do not transmit epoch starts. Epochs are thus identified as "air" epochs or as "ground" epochs, depending on the source of the epoch-start triads. For fine synchronization the airborne process differs from that of a ground station in that the fine-synchronization timing-pulse triads are transmitted only to those equipments whose time-base error is likely to be greater than the time-base error of the synchronization donor. The previously mentioned biphase message in the range pulse is used to transmit the indication of time-base error (hierarchy) and to address a synchronization request to a specific donor. This air-to-air synchronization capability permits the extension of synchronized operation to areas quite remote from the ground stations and reduces the number of ground stations required.

Each system assesses its own time-base error as a function of (1) the error indicated by the donor from which synchronization is obtained, (2) the elapsed time since the last resynchronization was obtained, and (3) the stability of the oscillator used for timing. This system time-base error (or accuracy) is expressed as a hierarchy number over the range from zero to 63. Ground stations, being the source of master time, have a hierarchy of zero. A system obtaining fine synchronization from a ground station will adopt a hierarchy one larger than the ground station, e.g., one. Hierarchy can be chained from aircraft to aircraft, with each step increasing the hierarchy by one until hierarchy 63, at which point the probable error in the time base of the last system will be equal to the maximum permitted error of 2 microseconds. An airborne system will always request synchronization from the lowest-hierarchy donor that can be heard.

If a period of time passes without receipt of fine synchronization, a CAS will demote its hierarchy by one for each estimated increase of 0.05 microsecond in time-base error. Upon demotion beyond hierarchy 40, i.e., an error of two microseconds, the system will revert to the back-up mode or will cease to transmit. The time to demote to beyond hierarchy 40 is a function of the stability of the reference oscillator. An atomic oscillator with stability of one part in 10^{11} will take 55-1/2 hours, while a crystal oscillator having the least acceptable stability of two parts in 10^{8} will take 2-1/2 minutes.

SYNCHRONIZATION OF LIMITED SYSTEMS

To make the collision-avoidance system available to general aviation, several levels of limited-capability systems have been defined that are less expensive than full systems while still affording cooperative collision-avoidance operation.

The feature of limited systems that alters the fine-synchronization process is the elimination of the biphase modulation and its associated logic circuitry. Thus a limited system's participation in the fine-synchronization process is as a recipient only. A limited system cannot be permitted to transmit fine synchronization, because it cannot make its synchronization error known to a potential requester. Because of its inability to transmit biphase, a limited system cannot request fine synchronization from a specific donor. The absence of biphase modulation identifies limited systems to ground stations and full systems. To provide fine-synchronization support to limited systems, the ground stations are designed to provide fine-synchronization replies in ground epochs and the full system is designed to provide fine-synchronization replies during air epoch to equipments that have no biphase modulation in their transmissions. To reduce the occurrence of interference resulting from multiple full systems providing replies, a full system, instead of replying to all such transmissions, will reply with a probability of 1/n, where n is the number of full systems that can be heard.

BACK-UP MODE OPERATION (BUM)

Full systems and the highest-level limited systems are provided with an asynchronous mode of operation, termed the back-up mode, to afford collision protection in geographical areas in which master time is unavailable. The back-up mode employs an interrogator-responder technique for the exchange of collision-avoidance data. Back-up mode operation is conducted only on the F-1 frequency so that the system can be listening for epoch-start triads. The altitude pulse transmitted in back-up mode is changed to a pulse duration of 16.4 microseconds for the purpose of mode identification. The 200-microsecond range pulse and the three-second epoch are retained. An aircraft receiving a back-up mode transmission is unable to measure range because of the lack of a common time base, but it can measure altitude and range rate. If the altitude difference indicates a potential threat, the receiving aircraft responds with a back-up mode warning pulse and a back-up mode maneuver pulse. The time of the transmission of the warning pulse and the maneuver pulse is shown in Figure A-10. The receiving aircraft transmits the warning pulse at a time such that it will arrive at the transmitting aircraft less than 2951 microseconds after the time it transmitted its range pulse if the aircraft are within the bounds of the protection envelope. The delay between the warning and maneuver pulses is coded as shown to inform the transmitting aircraft of the aircraft above/below or to instruct the transmitting aircraft to climb/dive. The climb/dive coding is used if the altitude difference is 800 feet or less. The aircraft above/below coding is used if the altitude difference is greater than 800 feet but less than or equal to 3,200 feet. If the altitude difference is greater than 3,200 feet, the receiving aircraft does not reply.

MANEUVER COMMANDS

The T/F CAS threat logic is designed to provide a safe vertical separation between aircraft whose flight paths are approaching a hazardously close separation in the horizontal plane. The minimum altitude separation permitted by the logic (if all commands are executed) is 600 feet in operations below 10,000 feet or 800 feet in operations above 10,000 feet. To insure that complementary maneuvers are executed, the transmitted altitude is biased by 200 feet in the direction of the maneuver command if the altitude difference at the time the command is generated is less than 400 feet. Co-altitude threats also generate "no turn" commands so that the range rate will stabilize to permit an accurate assessment of the Tau zone. The protection-envelope boundaries are based on pilot and aircraft response times, on the tolerances within which the T/F CAS measures the parameters used to identify threatening aircraft, and on maneuver accelerations of 1/8g to 1/4g, with resulting vertical velocities of 2000 feet per minute, which are suitable for routine passenger operations.

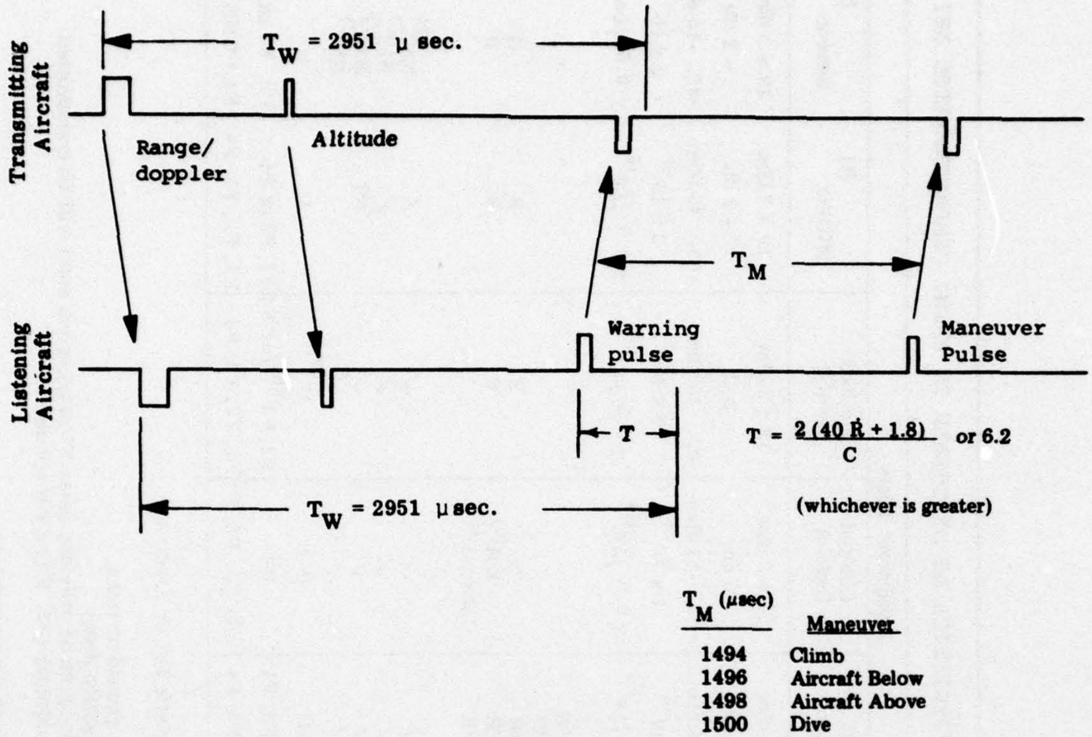


Figure A-10. T/F CAS BACK-UP MODE

T/F CAS HARDWARE

The types of T/F CAS equipments and their respective performance characteristics that are described in ARINC Characteristic 587, "Air Transport Time-Frequency Collision Avoidance System", are summarized in Table A-1. The MICRO system is not currently described in Characteristic 587; therefore, the characteristics shown for the MICRO system were added to the table with the performance parameters adjusted to agree with the other system types.

GROUND STATIONS

Ground stations provide the time base to which all airborne systems synchronize. They use atomic oscillators as their time standards, and all will be synchronized to within ± 0.5 microsecond of the average time of all ground stations. Ground stations synchronize airborne CAS equipment by transmitting precisely timed fine-synchronization pulse triads in response to synchronization requests from the airborne equipments.

Table A-1. T/F CAS EQUIPMENT TYPES AND CHARACTERISTICS AS DESCRIBED IN ARINC CHARACTERISTIC 587

Characteristics	Equipment Type: Ground Type	Full System	Limited Level 1	Limited Level 2	MICRO (1)	Beacon (2)
Transmitter Power	33 ± 3 dbw	30 ± 3 dbw	26 ± 3 dbw	19 ± 3 dbw	19 ± 3 dbw	19 ± 3 dbw
Cable Loss plus Antenna Gain	+ 5 db	- 2 db	0 db	- 2 db	- 2 db	- 2 db
Receiver Dynamic Range	-88, -15 dbm	-88, -15 dbm	-84, -13 dbm	-83, -15 dbm	-83, -15 dbm	-83, -15 dbm
Reference Oscillator Accuracy (min.)	1×10^{-12}	1×10^{-8}	2×10^{-8}	2×10^{-8}	2×10^{-8}	2×10^{-8}
Synchronization Accuracy	± 0.5 μs (3)	± 0.25 μs (4)	± 0.5 μs (4)	± 0.5 μs (4)	± 0.5 μs (4)	± 0.5 μs (4)
Transmit (T), Receive (R);						
Hierarchy	T	T/R				
Fine-Synchronization Address	NA	T/R				
Fine-Synchronization Replies	T	T/R	R	R	R	R
Epoch-Start Triads	T	T/R	T/R (5)	R	R	R
Back-Up Mode	NA	T/R	Optional (5)			
Protection Envelope Parameters;						
Range (R)	NA	✓	✓	✓	✓	NA (2)
Altitude Difference (ΔH)	NA	✓	✓	✓	✓	NA (2)
Range Rate ($\dot{R}$)	NA	✓	✓	✓	(8)	NA (2)
Altitude Rate ($\dot{H}$)	NA	✓	✓	✓		NA (2)
Antennas; Upper (U), Lower (L)	NA	U&L	U-L	U (7)	U	U
Transmitted Frequencies	F1, F2, F3, F4	F1, F2, F3, F4	(6)	F2, F3 and/or F4	F2, F3 or F4	F2, F3 or F4
Received Frequencies	F1, F2, F3, F4	F1, F2, F3, F4	F1, F2, F3, F4	F1, F2, F3, F4	F1, F2, F3, F4	F1 + ONE

(1) The MICRO is not presently described in Characteristic 587 or ANTC 117.
(2) The beacon does not contain threat logic.
(3) Maximum time error with respect to average of all ground stations.
(4) Synchronization accuracy with respect to synchronization donor.
(5) Transmission of epoch-start triads optional, if back-up mode provided (uses F1 only), epoch start will be transmitted.
(6) Without back-up mode, transmission on only one frequency (F2, F3, or F4) optional.
(7) Use of two antennas optional.
(8) Incorporation of range rate is being contemplated by the manufacturers.

FULL SYSTEMS

In addition to performing the collision-avoidance function, full systems when operating in the synchronized mode also provide fine time synchronization to the lower-capability systems. They will provide fine synchronization to other full systems also but only if specifically addressed in the bi-phase message transmitted by the full system requesting fine synchronization. The transmission of fine synchronization by full systems permits accurate time synchronization to be propagated to aircraft that are considerably beyond communication range of a ground station. With the normal crystal oscillator a full system can operate in the synchronous mode for up to four minutes without receiving fine-synchronization support. This is adequate for operations within the continent, where the density of aircraft operations permits propagation of fine synchronization into areas relatively remote from ground stations. Full systems also have provisions for using atomic oscillators that will extend the period of synchronized operation to about 2-1/2 days. Full systems are provided with back-up mode capability for operations in areas in which fine-synchronization support is not available.

LIMITED EQUIPMENTS

These equipments do not modulate their transmissions with bi-phase nor do they decode bi-phase in any transmissions they receive. Because of the lack of bi-phase encoding and decoding, the limited systems receive fine synchronization, but they are incapable of supplying fine synchronization to other systems. Ground stations and airborne full systems interpret the lack of bi-phase to be an all-call request for fine synchronization, and they automatically respond to such transmissions with a fine-synchronization reply, as was discussed previously.

LIMITED SYSTEM, LEVEL 1

This category of equipment has several options that determine the capabilities of the equipment. With the maximum-capability options selected, the equipment differs from a full system only in reduced power output, lack of bi-phase, and a reduced specification on oscillator stability. It employs upper and lower antennas, is capable of transmitting on each of the four frequencies, can operate in the back-up mode, and transmits epoch-start triads when operating in the synchronized mode. With the minimum-capability options selected, the specifications very closely resemble those of the level-2 category equipment.

LIMITED SYSTEM, LEVEL 2

Equipment in this category has a further reduction in transmitted power and relinquishes some additional capabilities. It is incapable of transmitting on the F-1 frequency; therefore, it cannot operate in the back-up mode and it does not transmit epoch-start triads. At the option

of the user, the equipment can be configured to transmit on any of the three remaining frequencies or it can be configured to transmit on only one of the three frequencies.

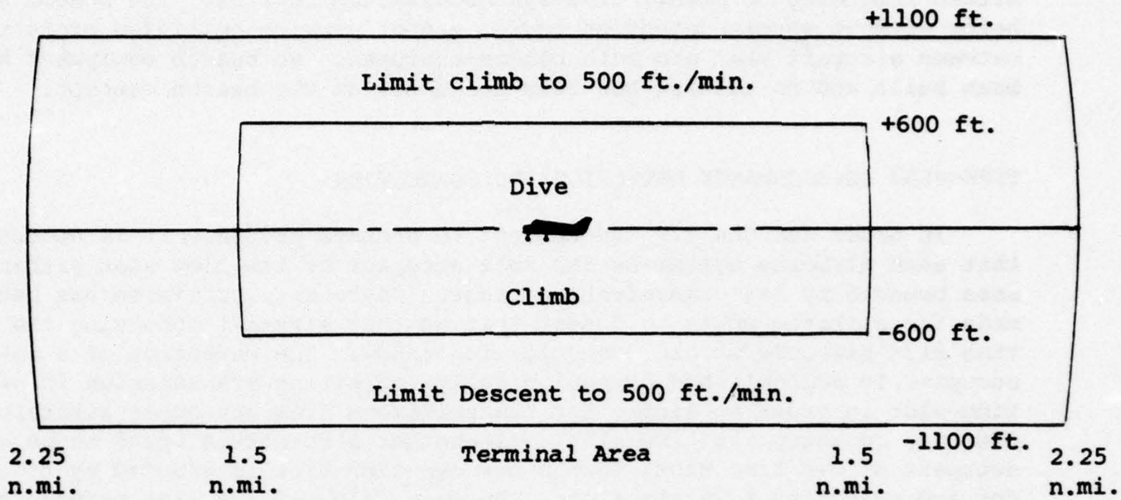
LIMITED EQUIPMENT, MICRO CAS

This category of equipment is not described in ARINC Characteristics 587. The MICRO CAS was designed and built as a feasibility model of a low-cost equipment for installation in general-aviation aircraft in the lower price ranges. All of the previously described equipments derive range rate from the doppler shift in the frequency of received range pulses. Therefore, time-to-collision is one of the parameters used in establishing the horizontal extent of their protection envelopes. Conversely, the MICRO CAS does not measure range rate. Therefore, the horizontal boundaries of the protection envelope are fixed at 1-1/2 nautical miles for flying en route and at 1/2 nautical mile for flying in the traffic-pattern area of a terminal. Since the MICRO CAS was designed for aircraft of comparatively low performance, aircraft with this equipment would have no provision for extending the altitude boundaries of their protection envelopes when climbing or descending. The transmitter power of the MICRO CAS units provided for the flight test was 23 dBw instead of the 19 ±3 dBw shown in the table. It transmits on only one of the three frequencies F-2, F-3, or F-4, and does not operate in the back-up mode.

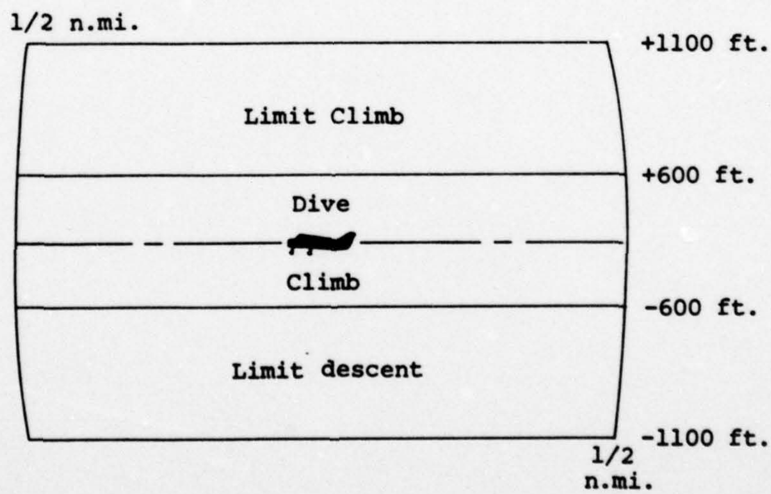
The protection envelope for the MICRO CAS as shown in Figure A-11 is a cylinder, centered on the aircraft, with a radius 1.5 nautical miles in the horizontal and a depth of 600 feet above and 600 feet below the aircraft. This cylinder is the en route (normal) maneuver-command zone. If another aircraft penetrates this cylinder, the MICRO CAS will generate a dive command if the intruder is in the upper half of the cylinder or a climb command if the intruder is in the lower half. For operations in the traffic-pattern area of a terminal, the radius of the maneuver-command zone is reduced to 1/2 nautical mile to avoid undesirable alarms from properly spaced aircraft that are also in the traffic pattern. The maneuver-command zone is contained within a larger cylinder with a radius of 2.5 nautical miles and a depth of 1,100 feet above and 1,100 feet below the aircraft. That portion of the larger cylinder that is outside the maneuver-command zone is the warning zone. If another aircraft penetrates the upper half of the warning zone, the MICRO CAS generates a limit-climb advisory to the pilot. If the penetration is into the lower half of the warning zone, a limit-descent advisory is generated.

LIMITED SYSTEM, BEACON

The beacon CAS was conceived as a minimum-cost equipment that could be installed in general-aviation aircraft to permit aircraft having the higher levels of CAS equipments to detect the presence of the beacon-equipped aircraft to take the necessary avoiding action. The beacon system transmits the range pulse (without bi-phase) and the altitude pulse on one of the



(a) Normal Range



(b) Short Range

Figure A-11. MICRO CAS PROTECTION ENVELOPE

three frequencies F-2, F-3, or F-4. It receives F-1 to obtain epoch-start triads for coarse time synchronization, and it receives on its own transmitted frequency to obtain fine-synchronization replies. The beacon system, being without threat-detection logic, cannot provide collision protection between aircraft that are both beacon-equipped. No beacon equipment has been built, and no testing has been conducted on the beacon concept.

TIME-SLOT CO-OCCUPANCY DETECTION AND CORRECTION

In order for the T/F CAS concept to operate properly, it is necessary that each airborne system be the sole occupant of its time slot within the area bounded by its communication range. Therefore, provision has been made for airborne units to detect that another aircraft occupying the same time slot has come within communication range. The detection of a co-occupant is accomplished by periodically inhibiting transmission in own-time-slot in order to listen for transmissions from any other aircraft that also may be using the time slot. If another aircraft is found to be a co-occupant of own time slot, then a new own-time-slot is adopted by testing for and selecting a vacant slot. The mean value of the time between tests for co-occupancy has been selected to be 40 seconds.

AD-A054 697 ARINC RESEARCH CORP ANNAPOLIS MD F/G 1/2
TEST AND EVALUATION OF THE TIME/FREQUENCY COLLISION AVOIDANCE S--ETC(U)
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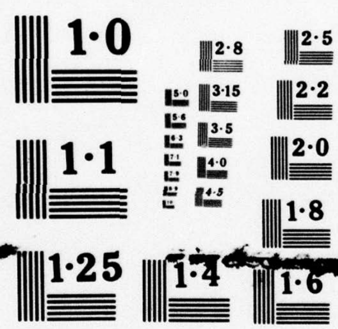

APPENDIX B

SAMPLE MISSION BRIEFING PACKETS

The briefings reproduced on the following pages are representative of those issued to participants during the T/F CAS flight tests by the DoD AIMS/TRACALS System Program Office, Electronic Systems Division.

ELECTRONIC SYSTEMS DIVISION

DOD AIMS/TRACALS SYSTEM PROGRAM OFFICE

MISSION BRIEFING FOR TEST 5954
AFETR OD 065, TEST CODE F, MISSION I
TWO AIRCRAFT ENCOUNTERS

OD 065 Figures 3410-15, 16, 17, 18, 19 and 20

OBJECTIVE: To probe the warning and alarm-zone boundaries for five specific closing rates for both the Full CAS and Micro-CAS systems.

Flight Profiles: As outlined on the attached diagrams.

Project restrictions: None.

Aircraft:
1. USAF C-131B, S/N 53-7819, CALL SIGN EROS 1: INTERCEPTOR ACFT
2. USAF C-131B, S/N 53-7804, CALL SIGN EROS 2, TARGET ACFT

EQUIPMENT AND INSTRUMENTATION:

1. Both aircraft will carry Model 2000 T/F CAS units (full).
2. Both aircraft will carry model 2002 T/F CAS units (micro).
3. Both aircraft will carry photo data panels for model 2002 CAS.
4. EROS 1 will carry ATA data instrumentation.
5. EROS 2 will carry Model 2000 CAS photo data panel.
6. A T/F CAS ground station will be operated from PAFB.

INSTRUMENTATION CONFIGURATION: See Attachment.

OPERATING PROCEDURES:

1. File IFR Flight Plan to R-2902A/METRO areas. Identify Test Number 5954 in "Remarks" section of Flight Plan.

2. When clear of Patrick Departure Control, contact "Thinker One" on 264.8 (backup is 139.05).

3. "Thinker One" will clear you into the test area and pass you to "imitate One" (vector controller) on the same frequency.

4. Upon completion of the mission, checkout with "Thinker

One" and in with Patrick Approach Control to return to PAFB for landing.

5. The Aircraft Commander of EROS 1 is designated mission commander for this test. He is responsible for coordinating flight activities between aircraft.

6. From time to time IMITATES 1 will call out altitude differences. If altitude difference decreases to 200 ft, EROS 2 will climb to maintain 400 ft separation.

CALL SIGNS:	CALL	FUNCTION	FREQUENCY
	EROS 1	CREW, C-131B 819	264.8
	EROS 2	CREW, C-131B 804	264.8
	RAVEN 1	PROJECT, C-131B 819	349.6
	RAVEN 2	PROJECT, C-131B 804	349.6
	EROS ALPHA	TEST CONDUCTOR	349.6, SRO MOPS
	EROS BRAVO	GROUND CAS STATION	349.6, SRO MOPS
	THINKER 1	SRO	264.8
	IMITATE 1	VECTOR CONTROLLER	264.8

FLIGHT SAFETY RESTRICTIONS: SEE ATTACHMENT

TEST PROCEDURES:

1. Following engine start each aircraft commander will turn on CAS equipment power.

2. EROS BRAVO will verify proper operation of CAS units from ground sync station and will notify RAVEN 1 and RAVEN 2 on frequency 349.6 that "Project releases both aircraft for flight."

3. Aircraft will stage to test area in accordance with operating procedures above.

4. Fly to the test area, join in formation at 2,000 ft MSL and check altimeter calibration.

6. Enroute to the test area the project personnel will synchronize Epoch Counters on frequency 349.6 by the following procedure:

Raven 1 and Raven 2 shall declare "(call sign)ready to synchronize."

After hearing that both are ready, EROS Bravo shall declare: "Stand by to synchronize on my mark; 3, 2, 1, MARK! Acknowledge."

Raven 1 and Raven 2 shall report synchronization action accomplished.

7. EROS 1 shall direct project radio silence on 264.8 and all project communication shall be on 349.6 MHz.

8. IMITATE 1 shall direct EROS 1 to descend to 1800 ft MSL.

IMITATE 1 shall direct EROS 2 to climb to 2200 ft MSL.

9. IMITATE 1 will direct the aircraft into a tail-chase pattern (Fig. 3410-15) with EROS 1 at 180 knots and EROS 2 at 150 knots.

10. IMITATE 1 will announce 2 minutes to encounter.

11. IMITATE 1 will announce 1 minute to encounter.

12. EROS 1 will confirm visual contact at this time. If EROS 1 does not have visual contact with EROS 2 at this time, the aircraft commander will direct "BREAKAWAY, BREAKAWAY, BREAKAWAY" in accordance with the attached FlightSafety Restrictions.

13. After the encounter, EROS 1 will reduce speed to 150 knots at the direction of IMITATE 1.

14. IMITATE 1 will direct aircraft into a 30 knot closing-rate scissors pattern (figure 3410-16).

15. IMITATE 1 will announce 2 minute to encounter.

16. After the encounter, IMITATE 1 will direct the aircraft into a 100 knot closing-rate scissor pattern (figure 3410-17).

17. IMITATE 1 will announce 2 minute to encounter.

18. After the encounter, IMITATE 1 will direct the aircraft into 200 knot closing-rate scissors pattern (figure 3410-18).

19. IMITATE 1 will announce 2 minute to encounter.

20. After the encounter, IMITATE 1 will direct the aircraft into a second 200 knot closing-rate scissors pattern (figure 3410-19).

21. IMITATE 1 will announce 2 minute to encounter.

22. After the encounter, IMITATE 1 will direct the aircraft to the 420 knot closing rate maneuver (figure 3410-20).

23. IMITATE 1 will announce 90 seconds to encounter.

24. The aircraft will continue in the race track two more times to provide a total of three encounters at the 420 knot closing rate.

25. At the end of the 420 knot closing rate encounter, IMITATE 1 will direct the aircraft back to tail chase pattern (figure 3410-15). Both aircraft will accelerate to 180 knots.

26. Upon direction of the vector controller, EROS 1 will descend to 1500. EROS 2 will climb to 2500 ft.

27. The aircraft will repeat step 9 through 24 at the new altitude.

28. After the last of these encounters, the aircraft will be released to Patrick approach for return to Patrick AFB.

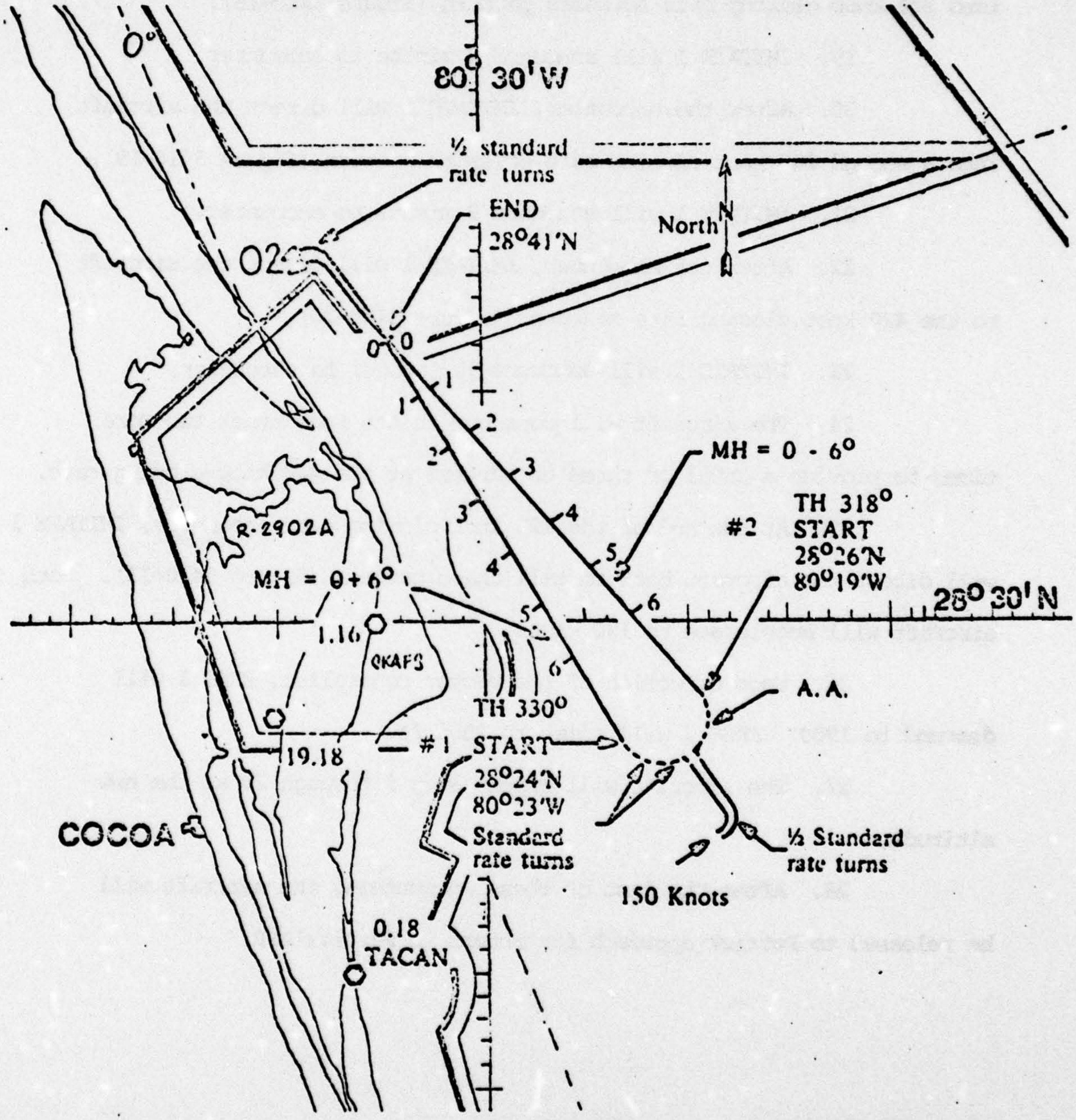

FIG 3410-16 TWO AIRCRAFT ENCOUNTERS 30 KNOT CLOSING RATE FROM SIDE (MISSION NO. 1 - 7)

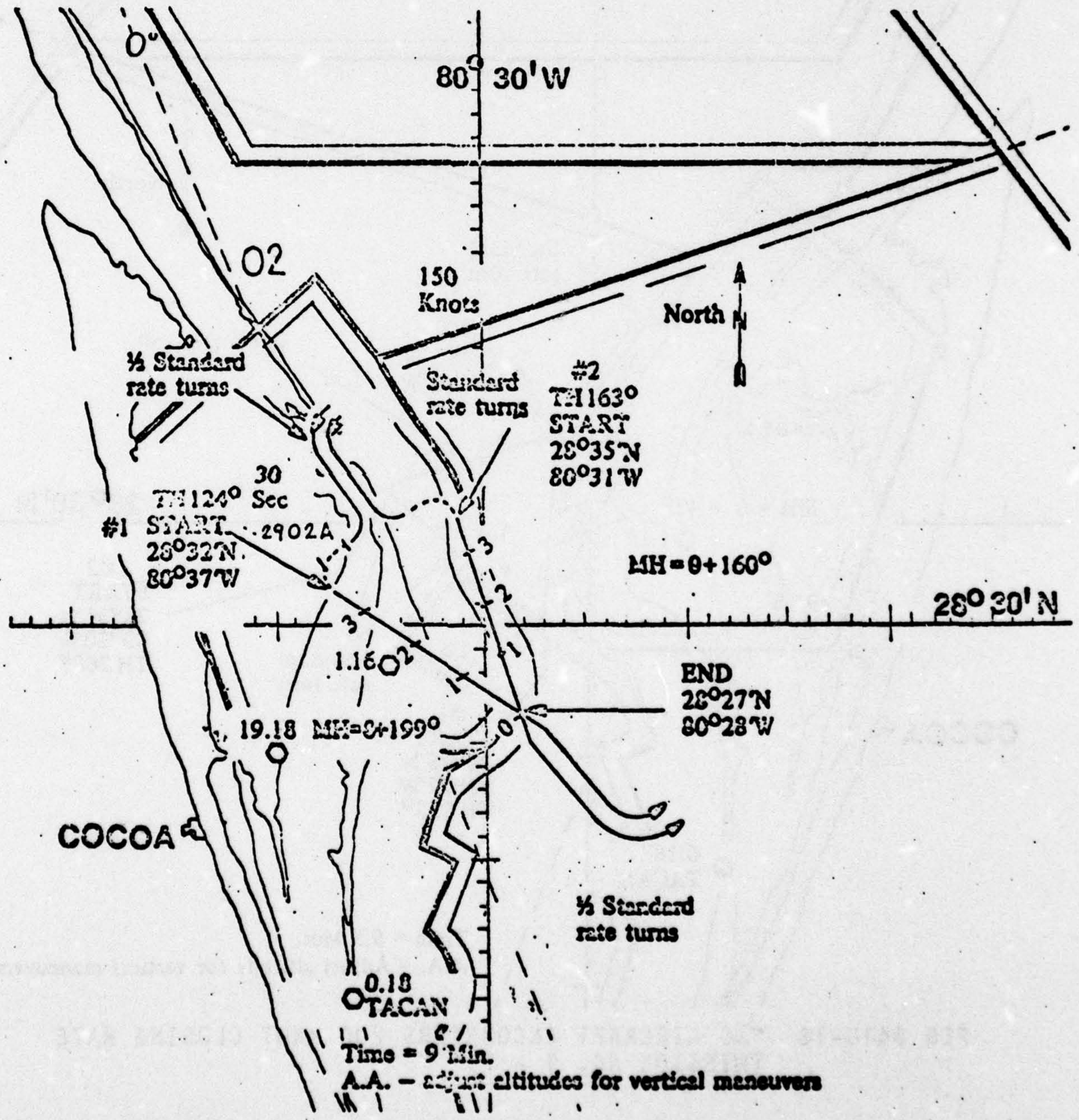

FIG 3410-17 TWO AIRCRAFT ENCOUNTERS 100 KNOT CLOSING RATE (MISSION NO. 1 - 7)

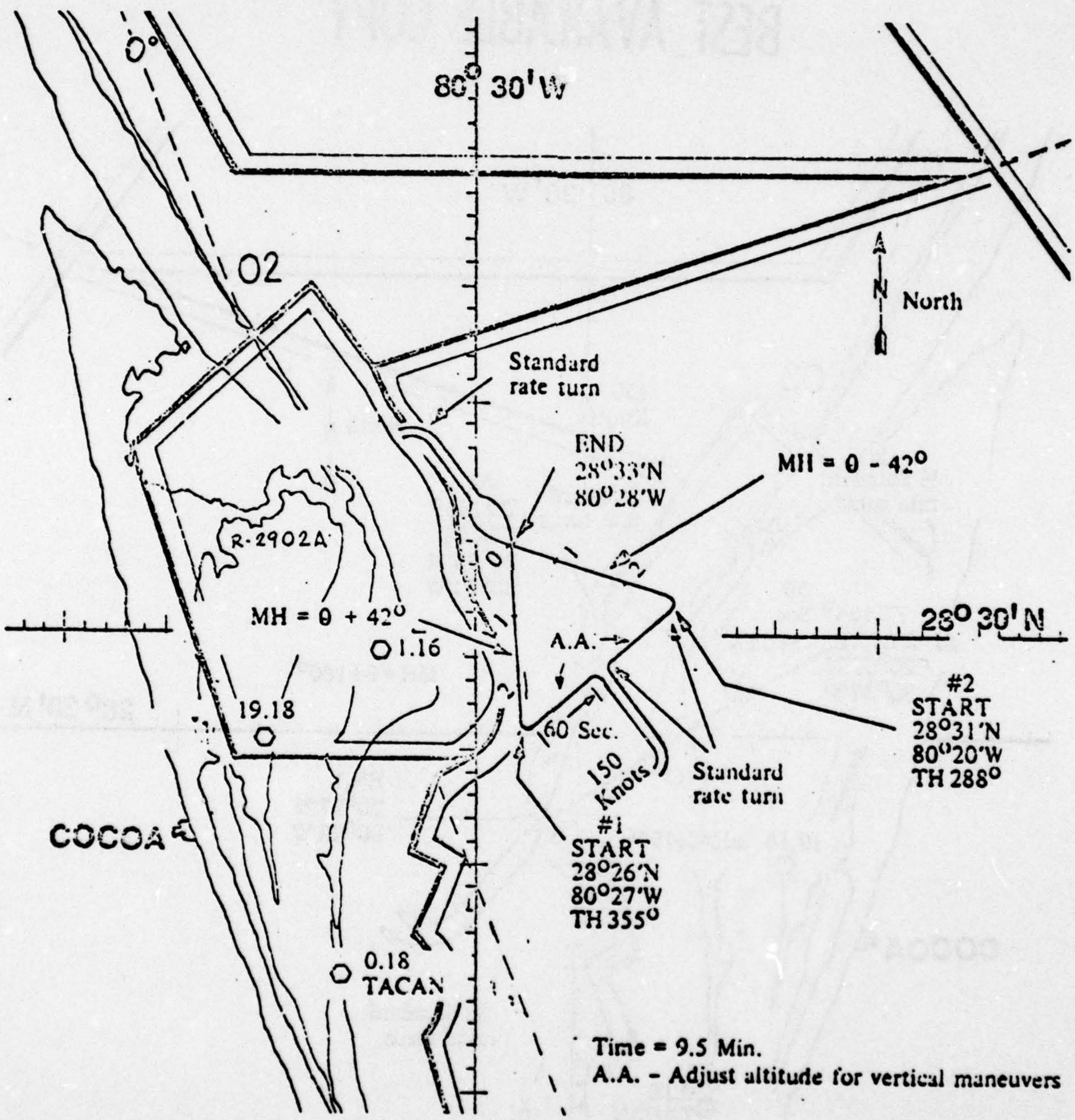

FIG 3410-18 TWO AIRCRAFT ENCOUNTERS 200 KNOT CLOSING RATE (MISSION NO. 1 - 7)

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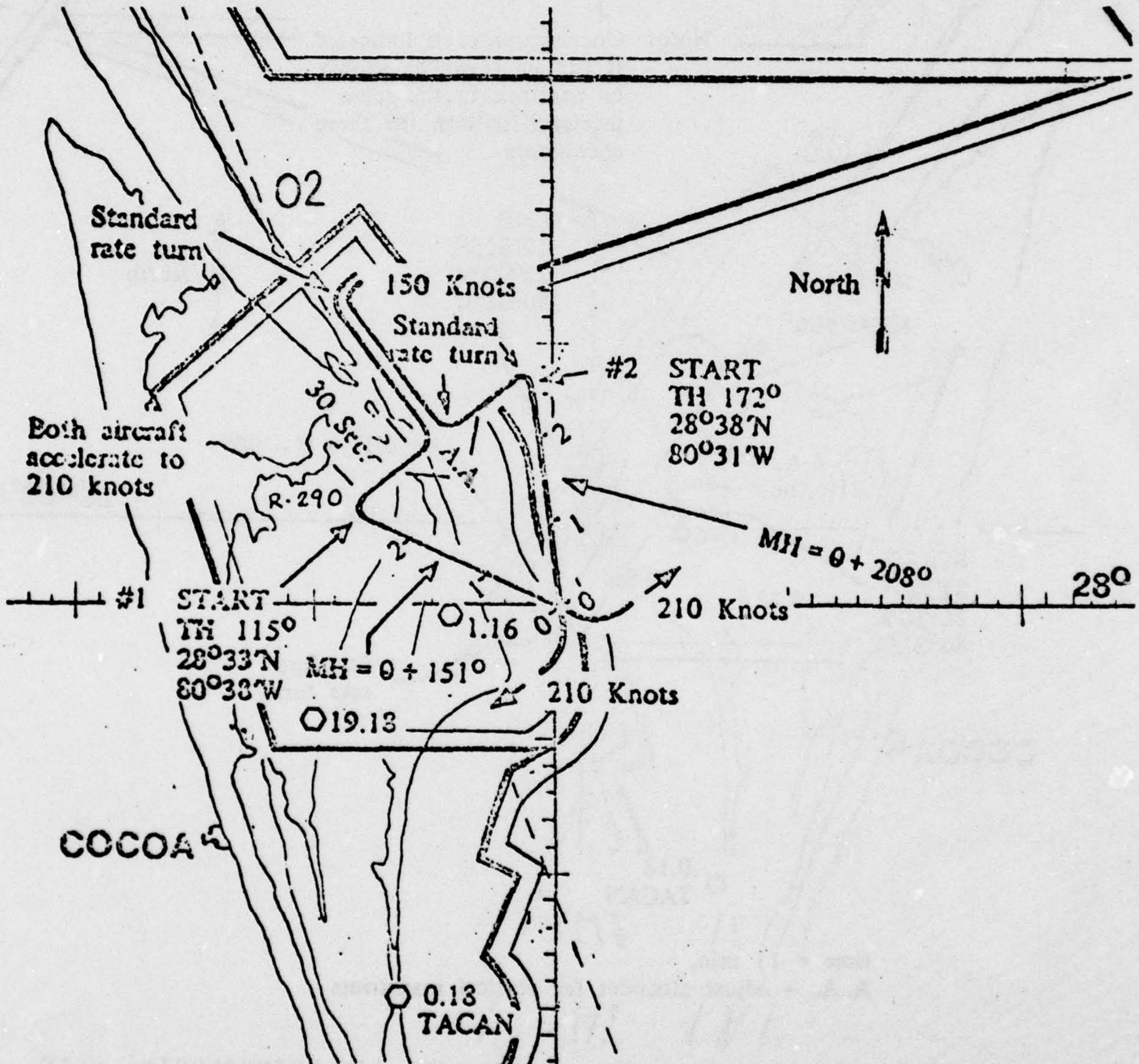

Time = 6 Min.
A. A. - Adjust altitudes for vertical maneuvers
Note: Aircraft should go directly into 420 knots closing rate case

FIG 3410-19 TWO AIRCRAFT ENCOUNTERS 200 KNOT CLOSING RATE AT ALTERNATE CONVERGING ANGLE (MISSION NO. 1 - 7)

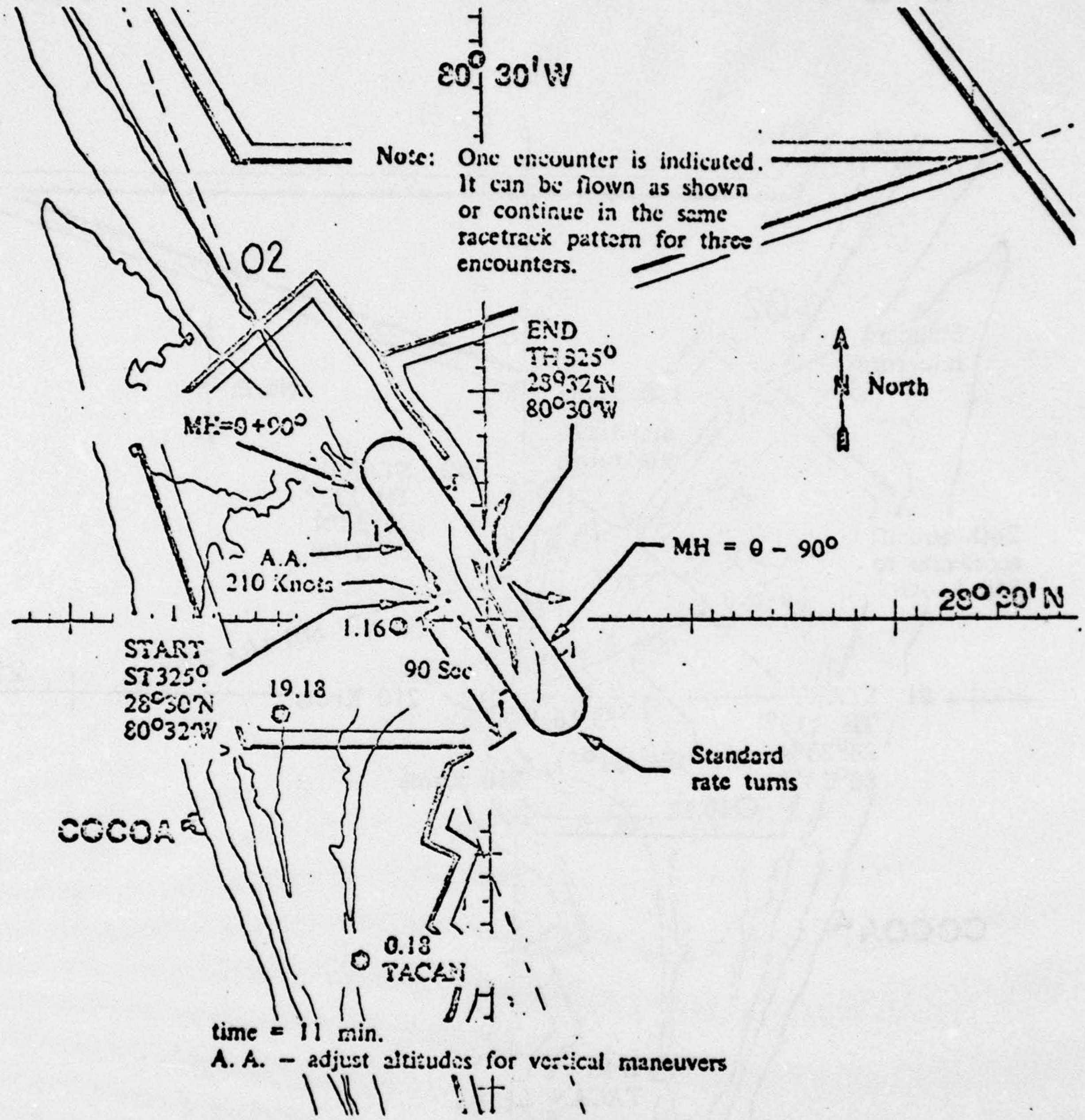

FIG 3410-20 TWO AIRCRAFT ENCOUNTERS 420 KNOT CLOSING RATE (MISSION NO. 1 - 7)

FLIGHT SAFETY RESTRICTIONS:

1. Prime responsibility for insuring positive aircraft separation shall rest solely with the aircraft commander of each aircraft.

2. It is to be specifically understood that instructions from the Vector Controller (call sign IMITATE) are solely concerned with aligning aircraft to gather data required by the project. Ground personnel will have no responsibility for insuring positive aircraft separation.

3. The vector controller will call a three mile "mark" over the air/ground channel as an aid to the aircrews.

4. When any individual involved in this test at any time detects an unsafe situation, he shall declare over the air-ground voice channel in use: "UNSAFE, UNSAFE, UNSAFE". Upon receipt of this warning, aircraft commanders will initiate breakaway.

5. When either aircraft commander involved in this test decides that an unsafe situation is developing he shall immediately initiate breakaway and declare to the other pilot over the air/ground channel: "BREAKAWAY, BREAKAWAY, BREAKAWAY".

6. If aircraft do not have visual contact with each other at 30 seconds or less the aircraft will direct "BREAKAWAY, BREAKAWAY, BREAKAWAY" in accordance with the Breakaway procedures. At the 1000 ft separation, only one aircraft needs visual contact on the other.

BREAKAWAY PROCEDURES:

C-131B S/N 53-7804, call sign EROS 2, shall climb at the maximum safe rate attainable to 3,000 ft MSL.

ELECTRONIC SYSTEMS DIVISION

DOD AIMS/TRACALS SYSTEM PROGRAM OFFICE

MISSION BRIEFING FOR TEST
AFETR OD 065, TEST CODE L, MISSION 7
TWO AIRCRAFT ENCOUNTERS

OD 065 Figures 3410-15, 16, 17, 18, 19 and 20

OBJECTIVE: To probe the warning and alarm-zone boundaries for five specific closing rates for both the Full CAS and Micro-CAS systems.

Flight Profiles: As outlined on the attached diagrams.

Project restrictions: None.

Aircraft: 1. USAF C-131B, S/N 53-7819, CALL SIGN EROS 1: INTERCEPTOR ACFT

2. USAF C-131B, S/N 53-7804, CALL SIGN EROS 2, TARGET ACFT

EQUIPMENT AND INSTRUMENTATION:

1. Both aircraft will carry Model 2000 T/F CAS units (full).
2. Both aircraft will carry model 2002 T/F CAS units (micro).
3. Both aircraft will carry photo data panels for model 2002 CAS.
4. EROS 1 will carry ATA data instrumentation.
5. EROS 2 will carry Model 2000 CAS photo data panel.
6. A T/F CAS ground station will be operated from PAFB.

INSTRUMENTATION CONFIGURATION: See Attachment.

OPERATING PROCEDURE:

1. File IFR Flight Plan to R-2902A/METRO areas. Identify Test Number in "Remarks" section of Flight Plan.

2. When clear of Patrick Departure Control, contact "Thinker One" on 264.8 (backup is 139.05).

3. "Thinker One" will clear you into the test area and pass you to "imitate One" (vector controller) on the same frequency.

4. Upon completion of the mission, checkout with "Thinker

One" and in with Patrick Approach Control to return to PAFB for landing.

5. The Aircraft Commander of EROS 1 is designated mission commander for this test. He is responsible for coordinating flight activities between aircraft.

6. From time to time IMITATES 1 will call out altitude differences. If altitude difference decreases to 200 ft, EROS 2 will climb to maintain 400 ft separation.

CALL SIGNS:	CALL	FUNCTION	FREQUENCY
	EROS 1	CREW, C-131B 819	264.8
	EROS 2	CREW, C-131B 804	264.8
	RAVEN 1	PROJECT, C-131B 819	349.6
	RAVEN 2	PROJECT, C-131B 804	349.6
	EROS ALPHA	TEST CONDUCTOR	349.6, SRO MOPS
	EROS BRAVO	GROUND CAS STATION	349.6, SRO MOPS
	THINKER 1	SRO	264.8
	IMITATE 1	VECTOR CONTROLLER	264.8

FLIGHT SAFETY RESTRICTIONS: SEE ATTACHMENT

TEST PROCEDURES:

1. Following engine start each aircraft commander will turn on CAS equipment power.

2. EROS BRAVO will verify proper operation of CAS units from ground sync station and will notify RAVEN 1 and RAVEN 2 on frequency 349.6 that "Project releases both aircraft for flight."

3. Aircraft will stage to test area in accordance with operating procedures above.

4. Fly to the test area, join in formation at 10,000 ft MSL and check altimeter calibration.

6. Enroute to the test area the project personnel will synchronize Epoch Counters on frequency 349.6 by the following procedure:

Raven 1 and Raven 2 shall declare "(call sign)ready to synchronize."

After hearing that both are ready, EROS Bravo shall declare: "Stand by to synchronize on my mark; 3, 2, 1, MARK! Acknowledge."

Raven 1 and Raven 2 shall report synchronization action accomplished.

7. EROS 1 shall direct project radio silence on 264.8 and all project communication shall be on 349.6 MHz.

8. IMITATE 1 shall direct EROS 1 to descend to 9800 ft MSL.

IMITATE 1 shall direct EROS 2 to climb to 10200ft MSL.

9. IMITATE 1 will direct the aircraft into a tail-chase pattern (Fig. 3410-15) with EROS 1 at 180 knots and EROS 2 at 150 knots.

10. IMITATE 1 will announce 2 minutes to encounter.

11. IMITATE 1 will announce 1 minutes to encounter.

12. EROA 1 will confirm visual contact at this time. If EROS 1 does not have visual contact with EROS 2 at this time, the aircraft commander will direct "BREAKAWAY, BREAKAWAY, BREAKAWAY" in accordance with the attached FlightSafety Restrictions.

13. After the encounter, EROS 1 will reduce speed to 150 knots at the direction of IMITATE 1.

14. IMITATE 1 will direct aircraft into a 30 knot closing-rate scissors pattern (figure 3410-16).

15. IMITATE 1 will announce 2 minute to encounter.

16. After the encounter, IMITATE 1 will direct the aircraft into a 100 knot closing-rate scissor pattern (figure 3410-17).

17. IMITATE 1 will announce 2 minute to encounter.

18. After the encounter, IMITATE 1 will direct the aircraft into 200 knot closing-rate scissors pattern (figure 3410-18).

19. IMITATE 1 will announce 2 minute to encounter.

20. After the encounter, IMITATE 1 will direct the aircraft into a second 200 knot closing-rate scissors pattern (figure 3410-19).

21. IMITATE 1 will announce 2 minute to encounter.

22. After the encounter, IMITATE 1 will direct the aircraft to the 420 knot closing rate maneuver (figure 3410-20).

23. IMITATE 1 will announce 90 seconds to encounter.

24. The aircraft will continue in the race track two more times to provide a total of three encounters at the 420 knot closing rate.

25. At the end of the 420 knot closing rate encounter, IMITATE 1 will direct the aircraft back to tail chase pattern (figure 3410-15). Both aircraft will accelerate to 180 knots.

26. Upon direction of the vector controller, EROS 1 will descend to 9500 ft EROS 2 will climb to 10,500 ft MSL.

27. The aircraft will repeat step 9 through 24 at the new altitude.

28. After the last of these encounters, the aircraft will be released to Patrick approach for return to Patrick AFB.

FLIGHT SAFETY RESTRICTIONS:

1. Prime responsibility for insuring positive aircraft separation. shall rest solely with the aircraft commander of each aircraft.

2. It is to be specifically understood that instructions from the Vector Controller (call sign IMITATE) are solely concerned with aligning aircraft to gather data required by the project. Ground personnel will have no responsibility for insuring positive aircraft separation.

3. The vector controller will call a three mile "mark" over the air/ground channel as an aid to the aircrews.

4. When any individual involved in this test at any time detects an unsafe situation, he shall declare over the air-ground voice channel in use: "UNSAFE, UNSAFE, UNSAFE". Upon receipt of this warning, aircraft commanders will initiate breakaway.

5. When either aircraft commander involved in this test decides that an unsafe situation is developing he shall immediately initiate breakaway and declare to the other pilot over the air/ground channel: "BREAKAWAY, BREAKAWAY, BREAKAWAY".

6. If aircraft do not have visual contact with each other at 30 seconds or less the aircraft will direct "BREAKAWAY, BREAKAWAY, BREAKAWAY" in accordance with the Breakaway Procedures. At the 1000 ft separation, only one aircraft needs visual contact on the other.

BREAKAWAY PROCEDURES:

C-131B S/N 53-7804, call sign EROS 2, shall climb at the maximum safe rate attainable to 11,000 ft MSL.

APPENDIX C

ATA INSTRUMENTATION FOR T/F CAS

GENERAL

The ATA instrumentation was designed and built by the Martin-Marietta Corporation, Baltimore Division, for the T/F CAS flight-test program conducted in 1969-70 under the sponsorship of the Air Transport Association.

The instrumentation is made up of Honeywell Micro-PAC circuit cards mounted in Honeywell Micro-BLOC mounts with a wirewrap backplain. The memory is the Honeywell ICM-42 core stack memory with a capacity of 2048 words of seven bits each. The digital electronics are contained in two Honeywell chassis boxes. The remaining items which make up the ATA instrumentation are the power-distribution panel, the instrumentation control panel, the analog-to-digital converter, the seven-track digital recorder and the photo-panel which contains Nixie tube real-time displays, the CAS indicator, and some aircraft flight instruments. The photo-panel is photographed by a 35-millimeter instrumentation camera.

ATA INSTRUMENTATION OPERATION

The operation of the T/F CAS consists of a series of timed events that are sequentially generated by the participating T/F CAS equipments. The quality of the performance of the T/F CAS equipments is dependent on the precision of the timing of the generation and detection of these events. Therefore, a primary function of the instrumentation is to provide a high-resolution time base for recording the time of occurrence and to identify the events as they are generated or detected by the associated T/F CAS. Other functions of the instrumentation are to record associated data that are related to the timing of the events. The instrumentation also calculates selected parameters from the event times and displays them in real time so that the T/F CAS and isntrumentation can be monitored for proper operation.

The block diagram of the ATA instrumentation is shown in Figure C-1. The instrumentation receives the 5-MHz reference frequency generated by the CAS and doubles it to 10 MHz to obtain timing increments of 0.1 microsecond. This 10- MHz signal drives the master register and the A and B registers, which are slaved to the master register. The times of

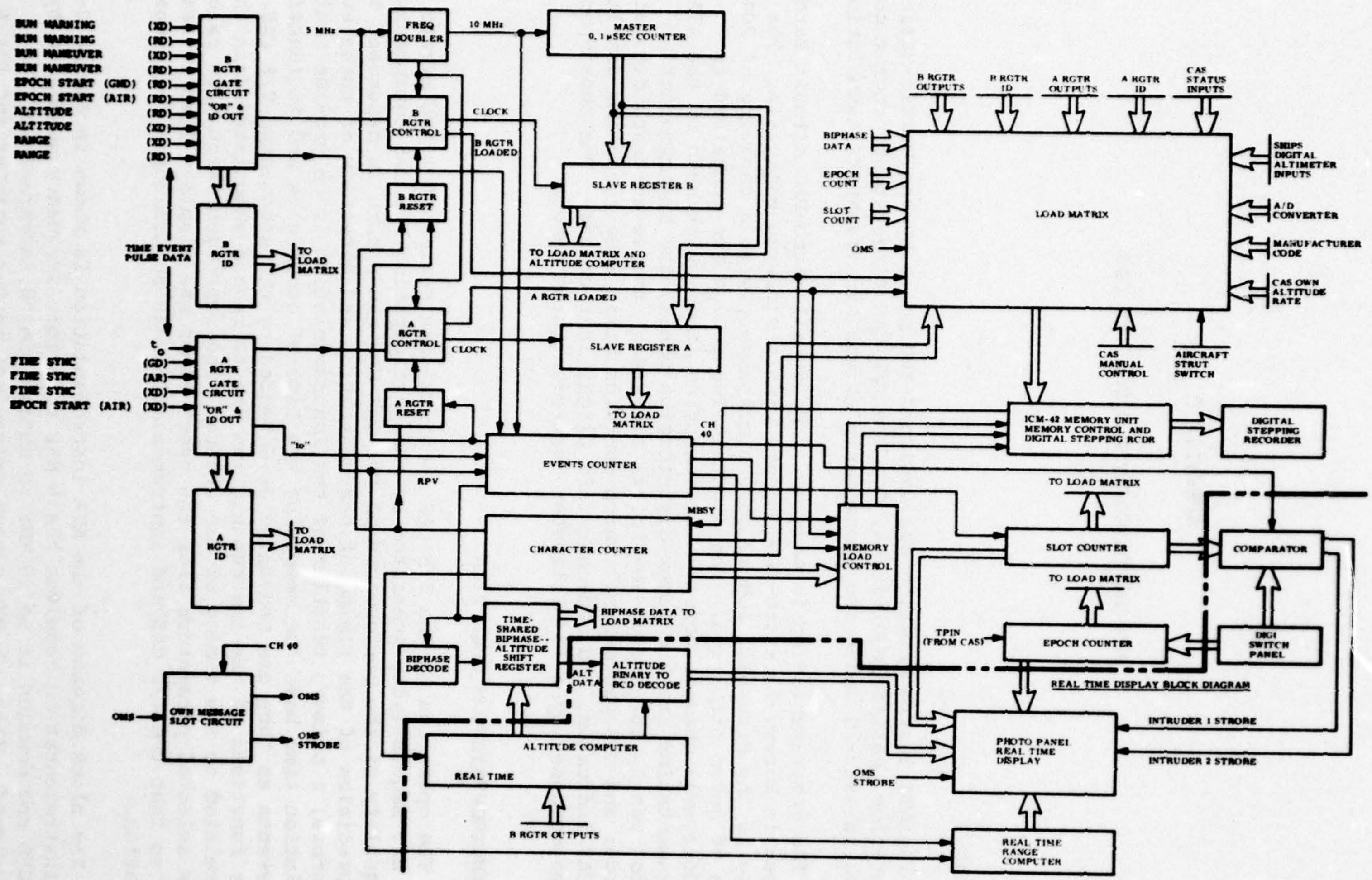

Figure C-1. INSTRUMENTATION SYSTEM BLOCK DIAGRAM

occurrence of events are obtained from the slave registers and are recorded with identifying data of type of event and the epoch number and slot number in which the event occurred. The timed events are listed below with the associated slave register identified. These events appear at the top-left of the block diagram.

Event	Slave Register	Time Slot
Little Tee (LT or t_o)	A	Every Slot
Range Pulse Trans. (RPXD)	B	Own Slot
Altitude Pulse Trans. (ALXD)	B	Own Slot
Fine Synch. Recd., Gud (TSGD)	A	Own Slot
Fine Synch. Recd., Air (TSAR)	A	Own Slot
BUM Warn Recd. (THWRD)	B	Own Slot
BUM Maneuv. Recd. (THMRD)	B	Own Slot
Range Pulse Recd. (RPRD)	B	Intruder Slots
Altitude Pulse Recd. (ALRD)	B	Intruder Slots
Fine Synch. Trans. (TSXD)	A	Intruder Slots
BUM Warn Trans (THWXD)	B	Intruder Slots
BUM Maneuv. Trans. (THMXD)	B	Intruder Slots
Epoch Start Trans. (TPXD)	A	Lead Slot (0000)
Epoch Start Recd., Gnd (BTRD)	B	Lead Slot (0000)
Epoch Start Recd., Air (TPRD)	B	Lead Slot (0000)

Other data are recorded which are related to the equipment performance or are required to correlate the data with data collected from the other equipments.

<u>Epoch Number</u> - An epoch counter counts the number of epochs since the counter was reset. This number is recorded with each lead slot.

<u>Status Bits</u> - There were 54 bits provided in the original design to record information on aircraft status, CAS status, equipment modifications, etc. In this test program one bit was used for the strut switch position and 12 bits were used to record the number of active slots when the traffic simulation test was run. These bits are recorded in each slot, including the lead slot.

Slot Number - A slot counter is reset at the beginning of each epoch and stepped at the beginning of each of the next 1999 time slots. The slot number is recorded with each active slot.

Bi-Phase Data - The hierarchy and synchronization request address transmitted in, or read from, the range pulse is recorded with each active slot.

Digital Altitude - The coded altitude is recorded in the same bit pattern as received from the encoding altimeter.

Own-Altitude Rate - The altitude rate of own aircraft is recorded in the coded form as received from the CAS.

Range Rate - The range rate of the intruder is digitized by the analog-to-digital (A/D) converter and recorded with each active intruder slot.

There is provision for real-time display of selected data from two intruder slots and from own slot. By means of thumb-wheel digi-switches, any two intruder slots can be selected for real-time display. The information displayed is the slot number, the range to the intruder, and the altitude of the intruder. The slot number and the altitude being transmitted are displayed for own CAS. The number in the epoch counter is also displayed.

The data are collected in the sequence, and recorded on tape, as shown in the tape format of Figure C-2. At the beginning of each epoch a pulse (TPIN) is received from the CAS. The pulse (lower right of the block diagram) steps the epoch counter, resets the slot counter to 0000, and causes the Lead Code to be transferred to the memory to identify the lead slot of a new epoch. Simultaneously with TPIN, the Little Tee pulse (LT or t_o) is received; this occurs 15 microseconds after the beginning of each time slot. The arrival of LT stops the A Register, and the reading is transferred to the memory as "t_o time" and the A Register is resynchronized with the master. Two bits in the last character in the field identify air epochs and air epoch start transmitted. The next event occurring in a lead slot is the receipt of an epoch-start triad by the CAS; the B Register is stopped and the reading is transferred to the memory. Two bits in the last character in the field identify the epoch start as air or ground. The remaining fields, Slot Number, Epoch Number, and Status bits, are transferred to the memory, and the instrumentation is ready for the first active slot.

The next event to occur will be receipt from the CAS of Little Tee (LT) for slot number 0001. This stops the A Register, but the reading is not transferred to the memory unless an event occurs that stops the B Register, thus indicating an active slot. If a second event does not occur by 1,459 microseconds, the events counter, which was started by LT, resets the A Register so that the instrumentation will be ready for slot number 0002. This process continues until an active slot is encountered.

If the slot is active, the next event will be a range pulse, which will stop the B Register. The readings of the A and B Registers, the slot counter, and the first 12 status bits are transferred to the memory, and the A and B Registers are resynchronized. When a preloaded marker bit indicates that the bi-phase code is ready in the shift register, these data are transferred to the memory. The instrumentation then waits for the settling of the analog voltage from the CAS that represents range rate and for the receipt of an altitude pulse. When the altitude pulse stops the B Register, the reading is transferred to the memory; this is followed by the code from the encoding altimeter and by own-altitude rate from the CAS. At about this time the A/D converter is strobed to digitize the range rate. The instrumentation now waits for the fine-synchronization triad to arrive. When the fine-synchronization triad arrives, the A Register is stopped, the reading is transferred to the memory, and the A Register is resynchronized. The next 30 status bits are transferred to memory, and if the CAS is not operating in BUM, the B Register is read on the fly for the BUM Warning and Maneuver times and the last six status bits are transferred to memory. The range rate, which is waiting in the A/D converter, is transferred to memory; then the marker character, all zeros, which marks the end of the data for that time slot, is transferred to memory, and the instrumentation waits for the LT of the next time slot. If the operation is BUM, the instrumentation waits for and records the Warning time and Maneuver time, both from the B Register, and then completes the slot's record.

In order to prevent lock-up of the instrumentation due to waiting for an event that will not occur, there are time-outs that cause the process to step past the event in questions. In this case, the "data" can be identified because the register ID bit is not generated unless the register is stopped by the occurrence of an event.

The real-time display operation is conducted in parallel with the data-recording operation. The instrumentation has an oscillator that runs at 16.2 MHz, which yields one count equal to 0.01 nautical mile. When LT occurs, it gates these 0.01 n.m. pulses into a BCD counter. When the range pulse arrives, the gate is closed and the register count is held until the altitude has been completed. The real-time altitude display is accomplished somewhat differently because the altitude must be computed. Altitude is coded as a delay between the leading edges of the range pulse and the altitude pulse as shown in Figure C-3. When the range pulse stops the B Register, the reading is transferred to the altitude computer and 720 microseconds is added to it so that the value becomes the equivalent of zero feet. When the altitude pulse stops the B Register, the new reading is subtracted from the value in the computer. The value remaining in the computer is the altitude with a scale factor of 4 μsec = 1000 ft. The value is then divided by four, converted to BCD, and strobed into the real-time display along with the time-slot number if the thumb-wheel digiswitch setting matches that time-slot number.

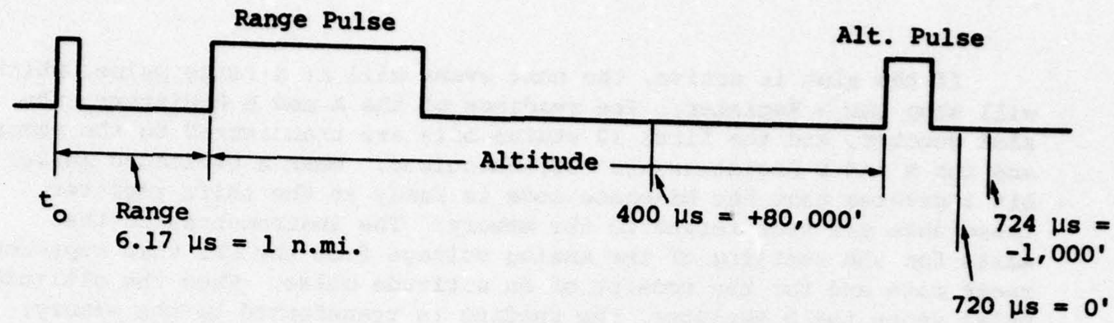

Figure C-3. ALTITUDE PULSE DELAY

APPENDIX D

McDONNEL DOUGLAS RELIABILITY AND MAINTAINABILITY REPORT

This appendix presents the CAS Model 2000 and 2002 reliability and maintainability report as prepared by McDonnell Douglas for the seven circuit failures that were detected in Florida.

Two supplemental failure reports and a revised tabulation of all nine failures appear at the end of this appendix.

RELIABILITY AND MAINTAINABILITY REPORT

MODEL 2000 AND 2002 COLLISION AVOIDANCE SYSTEMS

During the time period from 6 March through 28 March 1973, thirty (30) flights were flown from Patrick Air Force Base to test various combinations of the Model 2000 and 2002 Collision Avoidance Systems (CAS) in a variety of simulated airport and enroute traffic situations.

Counting preflight time, the Model 2000 CAS operated for a combined total of 113 hours and the Model 2002 for a combined total of 106 hours at Patrick Air Force Base. During the 219 hours of operation, four failures were experienced on the Model 2000 CAS and two failures on the Model 2002 Micro CAS. A third incident for the Model 2002 is recorded on the Failure Report form (see CAS-003) because data could be affected, however, the problem was a design deficiency rather than a failure and therefore will not be treated as a failure.

Table 1 is a compilation of the operating hours of the Model 2000 and 2002 CAS with an indication of when the failures occurred. Failure Reports 001 through 007 give a detailed account of the failures and corrective action.

Three of the four failures experienced on the Model 2000 CAS occurred during or immediately after operation on the F106. Considering the type service for which the Model 2000 was designed, the F106 is a hostile environment and the significance of such failures is difficult to assess. One failure (CAS-004) could have been the result of handling prior to installation, a second failure (CAS-007) was the result of vibration on a connector and the third failure (CAS-005) was an intermittent which has not reappeared since removal from the F106. The one failure (CAS-006) which occurred during usage aboard a C131 or C135 only was a relay which, due to previous failures, has already been removed from the production drawings of the Model 2000 CAS.

Of the two failures on the Model 2002 Micro CAS, one failure (CAS-001) was that of a malfunctioning integrated circuit and can be considered a chargeable failure. The other failure (CAS-002), was a broken wire on the hand wired integrated circuit board which has no paralled to a production configuration printed circuit board and therefore is of questionable significance.

Reviewing Table 1 and the Failure Reports, the Model 2000 CAS S/N 1 operated for 43 hours without failure; S/N 2 operated 8.5 hours prior to the relay failure and then continued the remaining 37 hours of service without failure; S/N 3 failed an integrated circuit lead connection almost immediately and then continued the remaining 11 hours of service without failure; and S/N 4 had an intermittent at 6 hours and a short at 11 hours, apparently as a result of vibration. The Model 2002 Micro CAS S/N 1 was used for 10 hours of ground operation without failure; S/N 2 was used for 1.5 hours of ground operation without failure; S/N 3 operated 35 hours prior to the failure of an integrated circuit and then continued the remaining 11.8 hours without failure; and S/N 4 operated 34 hours before a wire broke, after which it completed 12.8 hours of service without failure.

All failures were diagnosed, repaired and tested in 45 minutes or less.

M J Borrok

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W. H. Von Fange

W. H. Von Fange, Senior Group Engineer
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MJB/WHV/hgm

CAS OPERATING HOURS & FAILURES LOG

Date	Test No.	Code	Mission	MODEL 2000								MODEL 2002							
				S/N 1		S/N 2		S/N 3		S/N 4		S/N 1*		S/N 2*		S/N 3		S/N 4	
				Hours	FR	Hours	FR	Hours	FR	Hours	FR	Hours	FR	Hours	FR	Hours	FR	Hours	FR
3/5/73	3144	B	11/12	4.5/4.5		4.5/4.5				6.2/6.2		4.0/4.0				4.5/4.5		4.5/4.5	
3/7/73	4893	A	9					2.2/2.2	004	2.2/8.4	005								
(2 FLTS)								1.5/3.7		1.8/10.2									
3/8/73	4765	C	14	3.8/8.3		3.8/8.3										3.8/8.3		3.8/8.3	
3/12/73	5636	F	1			.6/8.9	006	1.5/5.2		.9/11.1	007					1.5/9.8		1.5/9.8	
(2 Tries)						2.4/11.3		2.4/7.6				2.0/6.0				2.4/12.2		2.4/12.2	
3/14/73	5719	D	8/10	5.0/13.3		4.6/15.9		4.6/12.2								4.6/16.8		4.6/16.8	
3/16/73	5954	F	1	4.7/18.0		4.7/20.6						3.5/9.5				4.7/21.5		4.7/21.5	
3/20/73	9386	G	2	4.9/22.9		4.9/25.5										4.9/26.4		4.9/26.4	
3/21/73	9302	H	3	2.5/25.4		2.5/28.0										2.5/28.9		2.5/28.9	
3/22/73	9224	I/L	4/7	5.1/30.5		5.1/33.1										5.1/34.0		5.1/34.0	
3/26/73	9718	J	5	5.5/36.0		5.5/38.6										5.5/39.5	001	5.5/39.5	002 003
3/27/73	9639	E	13	3.2/39.2		3.2/41.8										3.2/42.7		3.2/42.7	
3/28/73	9561	H/K	3/6	4.1/43.3		4.1/45.9						1.2/10.7		1.5/1.5		4.1/46.8		4.1/46.8	

NOTE: * = Ground Operation Only

FR = Failure Report No.

HOURS = Hours per Test/Hours accumulated

TABLE 1

MCDONNELL DOUGLAS ELECTRONICS COMPANY — **FAILURE REPORT** — **CAS - 001**

Dept. No. 1470	End Item Part No. & Suffix 2002	End Item Name Micro-CAS		Serial No. 003	Environment A/C 804	Supplement Yes ☐ No ☐	Malfunction 3, 2
	Test Type & Procedure No.		Para. Failed	Supplement Failure Report Numbers		Reported By D. Earne	

A

Description of Unit Malfunction (Symptoms)

During Mission #5, Micro CAS S/N 003 would not revert to STBY mode after 3 minutes of no synchronization.

B

Failure Verified Yes XX No ☐

☐ Adjusted

☒ Repaired

☐ Installed Replacement

Stamp

Description of Action

Found failed integrated circuit (E3) on A2 logic board. Replaced N7408A IC.

Analysis Time	Repair Time	Retest Time	Repaired by	Date
5 Min	5 Min	5 Min	D. Earnest	3 26

C

1st Level Subassy Part No. & Suffix	Part Name	Serial or Unit No.	Reported by	Date

Description of Unit Malfunction (Symptoms)

D

Failure Verified Yes ☐ No ☐

☐ Adjusted

☐ Repaired

☐ Installed Replacement

Stamp

Description of Action

Analysis Time	Repair Time	Retest Time	Repaired by	Date

REMARKS:

The failure of integrated circuit E3 disabled the mode control circuit which normally returned the Micro-CAS to the STBY mode within 3 minutes and 12 seconds after the last received SYNC pulse. The integrated circuit was a commercial grade, Signetics dual in-line type N7408A, which is a quadruple 2-input positive AND gate.

Elapsed operating time at Patrick Air Force Base was 35 hours, all of which was on board the C131 #804.

MCDONNELL DOUGLAS ELECTRONICS COMPANY

FAILURE REPORT

CAS - 002

	Dept. No.	Eng. Item Part No. & Suffix	End Item Name	Serial No.	Environment	Supplement	Malfunction
	1470	2002	Micro CAS	004	A/C 819	Yes ☐ No ☐	3 , 26
		Test Type & Procedure No.	Para. Failed	Supplement Failure Report Numbers			Reported by D. Farnest

A Description of Unit Malfunction (Symptoms)

Pre-flight check out revealed an inoperative LIMIT CLIMB display.

B Failure Verified Yes ☒ No ☐

☐ Adjusted
☒ Repaired
☐ Installed Replacement

Stamp

Description of Action

Wire was broken between integrated circuit E7-10 and F5-1 on A1 logic board. Wire was replaced.

Analysis Time	Repair Time	Retest Time	Repaired by	Date
10 Min	5 Min.	3 Min.	D. Farnest	3 , 26

C

1st Level Subassy Part No. & Suffix	Part Name	Serial or Unit No.	Reported by	Date

Description of Unit Malfunction (Symptoms)

D Failure Verified Yes ☐ No ☐

☐ Adjusted
☐ Repaired
☐ Installed Replacement

Stamp

Description of Action

Analysis Time	Repair Time	Retest Time	Repaired by	Date

REMARKS:

The Model 2002 Micro CAS units are feasibility models which were hand wired to simplify manufacture and facilitate easy modification. Failures because of broken wires in the integrated circuit wiring area have little, if any, relevance to a production model using printed circuits.

Elapsed operating time at Patrick Air Force Base was 34 hours, all of which was on board the C131 #819.

MCDONNELL DOUGLAS ELECTRONICS COMPANY

FAILURE REPORT

CAS - 003

Dept. No.	Eng Item Part No. & Suf.	Eng Item Name	Serial No.	Environment	Supplement Yes ☐ No ☐	Malfunction
1470	2002	MICRO CAS	004	A/C 819		3, 26

	Test Type & Procedure No.	Para. Failed	Supplement Failure Report Numbers	Reported By
				D. Earnest

A

Description of Unit Malfunction (Symptoms)

During Mission #5, Micro CAS S/N 004 would not move out of slot 1 when other Collision Avoidance Systems were in slots 2, 5 and 9.

B

Failure Verified Yes ☒ No ☐

Stamp

☐ Adjusted

☒ Repaired

☐ Installed Replacement

Description of Action

Design problem involving Own Message Slot (OMS), OMS +1 and Obstac: Avoidance Slot 15. Added a .0022 ufd capacitor from Integrated Ci: D5-2 to ground on A2 logic board.

Analysis Time	Repair Time	Retest Time	Repaired by	Date
30 min	5 Min	10 Min	D. Earnest	3, 26

C

1st Level Subassy Part No. & Suffix	Part Name	Serial or Unit No.	Reported by	Date

Description of Unit Malfunction (Symptoms)

D

Failure Verified Yes ☐ No ☐

Stamp

☐ Adjusted

☐ Repaired

☐ Installed Replacement

Description of Action

Analysis Time	Repair Time	Retest Time	Repaired by	Date

REMARKS:

With other CAS systems in slots 2, 5 and 9, Micro CAS S/N 4 which was transmitting on frequency f2 should have jumped from slot 1 to the next empty slot which would be slot 13. Bench tests showed that it did, in fact, move to slot 13 momentarily. However, at slot 15 the own slot memory was reset by a spike generated from a race problem involving the slot 15 obstacle avoidance gate signal and the slots 13 and 14 co-slot gate signal. The fix, which consists of the addition of a capacitor to delay the sensing of the slot 15 signal, prevents overlap of the gating signals, and thereby generation of the spike. This problem is obviously a design problem and cannot be reasonably counted as a failure. It was discovered only as result of a peculiar combination of slot occupancies which had not been experienced during bench tests.

Elapsed operating time at Patrick Air Force Base was 35 hours, all of which was on board the C131 #819

MCDONNELL DOUGLAS ELECTRONICS COMPANY

FAILURE REPORT

CAS - 004

Dept. No.	End Item Part No.	End Item Name	Serial No.	Environment	Supplement	Malfunction
1180	Model 2000	Collision Avoid. Sys.	3	A/C 069	Yes ☐ No ☐	3 7

	Test Type & Procedure No.	Para. Failed	Supplement Failure Report Numbers	Reported By
				J. Killinghar

A

Description of Unit Malfunction (Symptoms)

During mission #9 - system was observed to be transmitting hierarchy 00 and 77 on alternate epochs.

B

Failure Verified: Yes ☒ No ☐

Stamp:

☐ Adjusted
☒ Repaired
☐ Installed Replacement

Description of Action

Found a bad solder connection on flat pack F13 pin #5 of the A4 logic board.

Resoldered connection

Analysis Time	Repair Time	Retest Time	Repaired by	Date
20 Min	5 Min	5 Min	J. Willingham	3 7

C

1st Level Subassy Part No. & Suffix	Part Name	Serial or Unit No.	Reported by	Date

Description of Unit Malfunction (Symptoms)

D

Failure Verified: Yes ☐ No ☐

Stamp:

☐ Adjusted
☐ Repaired
☐ Installed Replacement

Description of Action

Analysis Time	Repair Time	Retest Time	Repaired by	Date

REMARKS:

Elapsed operating time at Patrick Air Force Base was approximately one (1) hour at the time of discovery and may have been present earlier. This unit was used for fit checks in Rome, N. Y., shipped to Patrick Air Force Base on board the C135, installed in F106 #069, removed and installed in the C131 #804, where it flew one flight non-powered, after which it was removed and reinstalled in F106 #069. The failure was observed during the first flight of the F106. Accidental rough handling during the sequence of installations and removals or shipping may have jarred loose the connection.

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MCDONNELL DOUGLAS ELECTRONICS COMPANY

FAILURE REPORT

CAS - 005

Dept. No.	End Item Part No. & Suffix	End Item Name	Serial No.	Environment	Supplement	Malfunction Date
1480	Model 2060	Collision Avoid. Sys.	4	A/C 075	Yes ☐ No ☐	3 , 7

	Test Type & Procedure No.	Para. Failed	Supplement Failure Report Numbers	Reported By
				J. Willingham

A

Description of Unit Malfunction (Symptoms)

Prior to mission #9 system was observed to display a 200 ft above and a no turn light continuously on the manuver indicator. Mission was flown with this failure.

B

Failure Verified Yes ☐ No ☒

Stamp

☐ Adjusted

☐ Repaired

☐ Installed Replacement

Description of Action

Checked system on bench after flight and no problem was found. Suspect Intermittent Pin connection between Mother & Daughter Board.

Analysis Time	Repair Time	Retest Time	Repaired by	Date
		20 Min.	J. Willingham	3 , 7

C

1st Level Subassy Part No. & Suffix	Part Name	Serial or Unit No.	Reported by	Date

Description of Unit Malfunction (Symptoms)

D

Failure Verified Yes ☐ No ☐

Stamp

☐ Adjusted

☐ Repaired

☐ Installed Replacement

Description of Action

Analysis Time	Repair Time	Retest Time	Repaired by	Date

REMARKS:

Elapsed operating time at Patrick Air Force Base was approximately 6.3 hours, all of which was on board F106 #075.

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MCDONNELL DOUGLAS ELECTRONICS COMPANY

FAILURE REPORT

CAS - 006

A

Dept. No.	End Item Part No. & Suffix	End Item Name	Serial No.	Environment	Supplement	
1480	Model 2000	Collision Avoid. Sys.	2	A/C 819	Yes ☐ No ☐	3, 13

Test Type & Procedure No.	Para. Failed	Supplement Failure Report Numbers	Reported By
			J. Willingham

Description of Unit Malfunction (Symptoms)

Unable to get flag indication of proper operation (stayed with barber pole indication).

B

Failure verified Yes ☒ No ☐

☐ Adjusted
☒ Repaired
☐ Installed Replacement

Stamp

Description of Action

System would not time out due to relay K2 failure on A1 Logic Boa

Analysis Time	Repair Time	Retest Time	Repaired by	Date
5 Min.	5 Min	5 Min	J. Willingham	3, 13,

C

1st Level Subassy Part No. & Suffix	Part Name	Serial or Unit No.	Reported by	Date

Description of Unit Malfunction (Symptoms)

D

Failure Verified Yes ☐ No ☐

☐ Adjusted
☐ Repaired
☐ Installed Replacement

Stamp

Description of Action

Analysis Time	Repair Time	Retest Time	Repaired by	Date

REMARKS:

The failed relay was a magnetic latching relay, Fifth Dimension P/N 6120-1C-24. Tests conducted after the manufacture of CAS Engineering Models 01, 02, 03 and 04 proved this relay to be unreliable; therefore, it has been removed from the production design of the Collision Avoidance equipment.

Elapsed operating time at Patrick Air Force Base was 8.5 hours, all of which was on boar the C131 #819.

McDONNELL DOUGLAS ELECTRONICS COMPANY

FAILURE REPORT

CAS - 007

A	Dept. No. 1480	End Item Part No. & Suffix Model 2000	End Item Name Collision Avoid. Sys.	Serial No. 4	Environment A/C 819	Supplement Yes ☐ No ☐	Malfunction 3, 13
		Test Type & Procedure No.	Para. Failed	Supplement Failure Report Numbers		Reported By J. Willingham	

Description of Unit Malfunction (Symptoms)

System would not transmit or receive.

B

Failure Verified Yes ☒ No ☐

Stamp

☐ Adjusted

☐ Repaired

☒ Installed Replacement

Description of Action

Found no transmitter drive or 1st L.O. Drive output from the excit
No cables or test equipment at remote site to isolate further - re
to St. Louis for repair.

Analysis Time	Repair Time	Retest Time	Repaired by	Date
10 Min.				3, 13,

C

1st Level Subassy Part No. & Suffix	Part Name	Serial or Unit No.	Reported by	Date
	Exciter		J. Willingham	3, 19,

Description of Unit Malfunction (Symptoms)

No transmitter drive or 1st L.O. output.

D

Failure Verified Yes ☒ No ☐

Stamp

☐ Adjusted

☐ Repaired

☐ Installed Replacement

Description of Action

Found +12 VDC intermittently shorted to ground at the connector on
X 4 X 2 board.

Put shrink fit sleeving over the connector terminal.

Analysis Time	Repair Time	Retest Time	Repaired by	Date
20 Min.	5 Min.	5 Min	W. W. Webb	3, 19, 7

REMARKS:

Elapsed operating time at Patrick Air Force Base was 11 hours, 10.2 of which was on board F106 #075. It was then installed in the C131 #819 to replace a failed unit. Preflight looked good but when aircraft taxied out for takeoff it failed.

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15 May 1973

RELIABILITY AND MAINTAINABILITY REPORT

ADDENDUM 1

MODEL 2000 AND 2002 COLLISION AVOIDANCE SYSTEM

Under date of 13 April 1973, the original reliability and maintainability report covering the 6 March thru 28 March Collision Avoidance System (CAS) tests at Patrick Air Force Base was submitted. Subsequenct Bench Testing at ARINC Research on 3 May uncovered a failure which is now known to have caused the anomalies observed during mission 5 on 26 March 1973.

After examining the data and the equipment is is now apparent that the system (Model 2000 S/N 2) decoded a ground bounce return from the altitude pulse which met the requirements of a resync triad. Due to a failure in a gating circuit which would normally reject the signal at that time in the slot, the system was allowed to use it.(Failure Report CAS-008). When tested on the bench, the failure was intermittent but reproducible. At the time of the failure, the airplane was traveling at low altitude and high speed which generated considerable buffeting. The model 2000 CAS S/N 2 had been operating for approximately 37 hours at Patrick Air Force Base at the time of the failure. It continued to operate until the end of the program for an additional 8.9 hours without a repeat of the incident. It should be noted that a failure of this nature may go undetected until a random backscatter reflection passes the remaining decoding criteria.

ELL DOUGLAS ELECTRONICS COMPANY

FAILURE REPORT

CAS- 008

Dept. No.	Unit Item Part No. & Suffix	Failed Item Name	Serial No.	Environment	Supplement	Malfunction Date
1480	Model 2000	Collision Avoid. Sys.	-	A/C 819	Yes ☐ No ☐	3, 26, 73

	Test Type & Procedure No.	Para. Failed	Supplement Failure Report Numbers	Reported By
				J. Willingham

A — Description of Unit Malfunction (Symptoms)

System accepted resync pulses at 813.0 and 823.6 microseconds into the time slot which, by design, should have been inhibited.

B — Failure Verified Yes ☐ No ☐ | Stamp

☐ Adjusted
☐ Repaired
☐ Installed Replacement

Description of Action

Found loose solder connection on pin 5 of integrated circuit All on the A2 logic board.

Analysis Time	Repair Time	Retest Time	Repaired by	Date
1 hr	2 Min.	15 Min.	J. Willingham	5, 3, 73

1st Level Subassy Part No. & Suffix	Part Name	Serial or Unit No.	Reported by	Date

C — Description of Unit Malfunction (Symptoms)

D — Failure Verified Yes ☐ No ☐ | Stamp

☐ Adjusted
☐ Repaired
☐ Installed Replacement

Description of Action

Analysis Time	Repair Time	Retest Time	Repaired by	Date

REMARKS:

The first occurance was at epoch #3190 (a Ground epoch) when a Ground resync triad was decoded. The system was transmitting and receiving on the lower antenna during own message slot (OMS) of that epoch.

The second occurance was at epoch #3855 (an air epoch) when a ground resync triad was decoded while having a hierarchy 00 in memory (Ground station sync request). The system was transmitting and receiving on the upper antenna during OMS of this epoch.

When bench tested, it was found that the enabling gate which normally extends from 1403.2 to 1439.2 microseconds to limit the acceptance of resync pulses to a narrow period of time had failed because of a loose connection, thereby enabling any resync pulse decoded during the entire OMS to be accepted. From past experience with EROS I, it has been found that when flying at low altitude the altitude pulse can be reflected from ground objects in such a manner that eventually one will look like a resync pulse. In the two instances covered by this failure report the airplane was flying at an altitude of 3700 feet and it is surmised that some object 7.5 n. miles away in the first case and 8.4 n. miles away in the second case reflected a signal which was accepted by the system because of a failure of the enabling gate signal. Elapsed operating time at Patrick Air Force Base was 37 hours, all of which was on board the C131 #819.

31 August 1973

RELIABILITY AND MAINTAINABILITY REPORT

ADDENDUM 2

MODEL 2000 AND 2002 COLLISION AVOIDANCE SYSTEM

Under date of 13 April 1973 the original reliability and maintainability report was submitted and on 15 May 1973 an addendum 1 was issued covering the Collision Avoidance System (CAS) tests at Patrick Air Force Base. Subsequent data reduction by ARINC Research in mid August uncovered another failure of the Model 2002, Micro CAS. This failure was not noticed during the flight test program as CAS indicators were not monitored during the tests.

The reduced data showed that one system transmitted altitudes which were in error by 150 to 350 ft and also used the same incorrect altitude for processing threats. The failure was traced to a flip flop which could not be placed in a preset state. The failed flip flop was from a shipment of plastic dual inline integrated circuits which has produced an abnormally large number of failures in recent months. The model 2002 Micro CAS S/N 3 had been in operation for approximately 17 hours at Patrick AFB at the detected time of failure. It continued to operate in this failed mode for the remainder of the test programs.

Table 1, originally prepared for the 13 April 1973 Reliability Report has been updated to reflect the Addendum 1 and 2 failures.

MCDONNELL DOUGLAS ELECTRONICS COMPANY

FAILURE REPORT

CAS - 009

Dept. No.	End Item Part No. & Suffix	End Item Name	Serial No.	Environment	Supplement	Malfunction Date
1470	2002	Micro CAS	003	A/C 804	Yes ☐ No ☐	3 , 16 , 73

	Test Type & Procedure No.	Para. Failed	Supplement Failure Report Numbers	Reported By
				Dr. K. Haspert, ARING

A

Description of Unit Malfunction (Symptoms)

The system processed and transmitted altitudes which were in error by 150 to 350 ft.

B

Failure Verified Yes ☐ No ☐

Stamp

☐ Adjusted

☐ Repaired

☐ Installed Replacement

Description of Action

Found a malfunctioning integrated circuit, C10 on the A2 board.

Analysis Time	Repair Time	Retest Time	Repaired by	Date
5 Min.	2 Min.	5 Min	D. Earnest	8 , 22 , 73

C

1st Level Subassy Part No. & Suffix	Part Name	Serial or Unit No.	Reported by	Date

Description of Unit Malfunction (Symptoms)

D

Failure Verified Yes ☐ No ☐

Stamp

☐ Adjusted

☐ Repaired

☐ Installed Replacement

Description of Action

Analysis Time	Repair Time	Retest Time	Repaired by	Date

REMARKS:

The symptom of failure was an apparent reversal of the C1 and C4 bits of the altitude code. The failed integrated circuit was a signetics N7476B dual inline flip flop which failed in a mode causing the set input to clock it to a reset state when the set line was released.

This failure was first noticed when reducing the data for Mission F on 3/16/73 which indicates an elapsed operating time at Patrick AFB of 17 hours, all of which were accrued on board the C131, tail #804.

CAS OPERATING HOURS & FAILURES LOG

Date	Test No.	Code	Mis-sion	MODEL 2000								MODEL 2002							
				S/N 1		S/N 2		S/N 3		S/N 4		S/N 1*		S/N 2*		S/N 3		S/N 4	
				Hours	FR	Hours	FR	Hours	FR	Hours	FR	Hours	FR	Hours	FR	Hours	FR	Hours	FR
3/4/73	3144	B	11/12	4.5/4.5		4.5/4.5				6.2/6.2		4.0/4.0				4.5/4.5		4.5/4.5	
3/7/73	4893	A	9					2.2/2.2	004	2.2/8.4	005								
(2 FLTS)								1.5/3.7		1.8/10.2									
3/8/73	4765	C	14	3.8/8.3		3.8/8.3										3.8/8.3		3.8/8.3	
3/13/73	5636	F	1			.6/8.9	006	1.5/5.2		.9/11.1	007					1.5/9.8		1.5/9.8	
(2 Tries)						2.4/11.3		2.4/7.6				2.0/6.0				2.4/12.2		2.4/12.2	
3/14/73	5719	D	8/10	5.0/13.3		4.6/15.9		4.6/12.2								4.6/16.8		4.6/16.8	
3/16/73	5954	F	1	4.7/18.0		4.7/20.6						3.5/9.5				4.7/21.5	009	4.7/21.5	
3/20/73	9386	G	2	4.9/22.9		4.9/25.5										4.9/26.4		4.9/26.4	
3/21/73	9302	H	3	2.5/25.4		2.5/28.0										2.5/28.9		2.5/28.9	
3/22/73	9224	I/L	4/7	5.1/30.5		5.1/33.1										5.1/34.0		5.1/34.0	
3/26/73	9715	J	5	5.5/36.0		5.5/38.6	008									5.5/39.5	001	5.5/39.5	002 003
3/27/73	9639	E	13	3.2/39.2		3.2/41.8										3.2/42.7		3.2/42.7	
3/28/73	9561	H/K	3/6	4.1/43.3		4.1/45.9						1.2/10.7		1.5/1.5		4.1/46.8		4.1/46.8	

NOTE:

* = Ground Operation Only

FR = Failure Report No.

HOURS = Hours per Test/Hours accumulated

TABLE 1

Revised 8/31/73

APPENDIX E

ANALYSIS OF VARIANCE

When a large quantity of data is available for analysis (such as range-rate error data), a common procedure is to summarize the data by using measures of central tendency and variability such as the mean and variance. However, the data may have been generated or collected in such a manner that it is possible to categorize the data with respect to certain factors, such as range, range rate, altitude, and altitude difference, and then calculate means and variances of the data points that fall into these various categories. If there were two different levels for each of the four factors, there would be a total of sixteen estimates of the mean and variance for the range error and range-rate error as shown in the following table.

Range Rate and Altitude	Altitude *Difference I*		Altitude *Difference II*	
	Range 1	Range 2	Range 1	Range 2
Range Rate I				
Altitude I	$\overline{\Delta R}$	$\overline{\Delta R}$	$\overline{\Delta R}$	$\overline{\Delta R}$
Altitude II	$\overline{\Delta R}$	$\overline{\Delta R}$	$\overline{\Delta R}$	$\overline{\Delta R}$
Range Rate II				
Altitude I	$\overline{\Delta R}$	$\overline{\Delta R}$	$\overline{\Delta R}$	$\overline{\Delta R}$
Altitude II	$\overline{\Delta R}$	$\overline{\Delta R}$	$\overline{\Delta R}$	$\overline{\Delta R}$

In all likelihood the mean values in each of the cells in the above table would not be exactly equal, because of sampling fluctuations or because of functional relationships between the means and the parameters of the experiments, or both. The analysis of variance will identify those experimental parameters that have a significant functional relationship with the observed mean values.

There is a valuable property of the variance that is used in the analysis of variance. If a set of data is divided into a number of groups, the variance of the set of data is equal to the sum of the component variances provided the groups are acting independently. This property of additiveness of variances is the underlying concept used in the statistical technique known as the 'analysis of variance' in which

the total variance of the set of data is broken down into its component parts and the relative importance of each component is assessed. Application of this technique to the analysis of the data enables one to determine if differences in mean values among the various cells and/or marginal mean values are significant or result simply from sampling fluctuations. Of course, if differences are significant, their magnitude must be examined to determine their technical impact.

To illustrate how this property can be used to analyze data, the following example of 12 observations was constructed (it is emphasized that the data are fictitious and are presented only to illustrate the analysis-of-variance technique):

TABLE OF INDIVIDUAL RANGE-RATE ERRORS ($\times 10^4$)		
Range Rate	Range	
	0-4 n.m.	Greater than 4 n.m.
Less than 100 kts.	896 1026 776	744 783 767
Greater than 100 kts.	636 781 649	569 606 509

TABLE OF AVERAGE RANGE-RATE ERRORS ($\times 10^4$)			
Range Rate	Range		
	0-4 n.m.	Greater than 4 n.m.	Average Overall Ranges
Less than 100 kts.	898.3	764.7	831.5
Greater than 100 kts.	688.7	561.3	625.0
Average overall range rates	793.5	663.0	728.2

In general, a two-way Analysis of Variance summary table based on the above data would be as follows:

Source of Variation	Degrees of Freedom	Sum of Squares	Mean Square	'F's
Between Ranges Rates	A-1	127926.75	127926.75	20.3
Between Ranges	B-1	51090.75	51090.75	8.1
Between Range and Range Rates	(A-1)(B-1)	28.93	28.93	.05
Residual	(n-1) AB	50447.92	6305.99	
Total	N-1	229494.25		

where A=B=2, the number of levels for each category; n=number of observations per cell; and N=12, the total number of individual observations. The sum of squares and the mean square would be computed as follows:

(1) Correction Factor

Obtain the total of all individual observations, square this total, and divide by the number of individual observations:

$$C = (\Sigma x)^2/N = 76370121/12=6364176.75$$

(2) Total Sum of Squares

Sum the squares of each individual observation and subtract the correction factor:

$$\Sigma x^2 - C = 6593671 - 6364176.75 = 229494.25$$

(3) Between Ranges Sum of Squares

Obtain the sum of the individuals for each of the range categories, square these totals, sum these squares, and divide by the number of individual observations in each total, and then subtract the correction factor from the total:

$$[(\Sigma X_{RI})^2 + (\Sigma X_{R2})^2]/6 - C$$

$$= [(4761)^2 + (3978)^2]/6 - 6364176.75$$

$$= 51090.75$$

(4) Between Range Rates Sum of Squares

Perform identical operation as with Between Ranges Sum of Squares:

$$[(4989)^2 + (3750)^2]/6 - 6364176.75$$

$$= 127926.75$$

(5) Range and Range-Rate Interaction

Obtain the sum for each of the cells, square these totals, sum these squares, and divide by the number of individual observations in each cell, and then subtract the correction factor and also subtract all high-order sums of squares, that is, the sums of squares for Range and Range Rate:

$$[(2695)^2 + (2294)^2 + (2066)^2 + (1684)^2]/3 - 6364176.75$$

$$- 51090.75 - 127926.75 = 28.93$$

(6) Residual Sum of Squares

The residual can be obtained by subtracting from the total sum of squares all the above-calculated sum of squares, or it can be calculated directly by adding the within sum of squares for each cell:

$$896^2 + 1026^2 + 773^2 - (2695)^2/3 + \ldots + 569^2 + 606^2 + 509^2 - (1684)^2/3$$

$$= 50447.92$$

The mean squares are obtained by dividing the sum of squares by their appropriate degrees of freedom.

In essence, using the analysis of variance reduces to determining whether the component of variance representing a particular source of variations is greater than the component of variance representing the residual or variance due to random fluctuation. The above example can be represented in tabular form as follows:

Source of Variation	Degrees of Freedom	Components of Variance
Range Rate	A-1	$\sigma_o^2 + n\sigma^2$ RxRR + $Bn^2{}_{RR}$
Ranges	B-1	$\sigma_o^2 + n\sigma_{RxRR} + An\sigma^2{}_R$
Range X Range Rate Interaction	(A-1)(B-1)	$\sigma_o^2 + n^2{}_{RxRR}$
Residual	(n-1) AB	σ_o^2

It is assumed that the variance component for the residual is a sum of squared linear functions of normal independent deviates that are independently distributed as $\chi^2\sigma_i^2$ with f_i degrees of freedom, where i stands for some particular line in the analysis-of-variance table.

Therefore, the ratio of the mean square is distributed as the 'F' distribution and provides the statistical test for determining whether the various components of variance are significant.

In the use of the above procedure it was assumed that each cell had an equal number of observations; otherwise, the formed ratios do not follow the 'F' distribution. Under these circumstances an analysis of variance is performed, with only the mean of the cell size being used, to obtain estimates of the mean squares, while the residual mean square is obtained from the original data.[1, 2] If the difference in cell sizes is large, this approach will lead to significant difference a greater part of the time then indicated by the significance level used.

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1) G. W. Snedecor, Statistical Methods, The Iowa State College Press, 1946.

2) S. R. Searle, Linear Models, John Wiley & Sons, Inc., 1971.

APPENDIX F

ANALYSIS OF THE EFFECTS OF FULL-CAS RANGE AND RANGE-RATE ERRORS

INTRODUCTION

In this appendix we develop a model for analyzing the effects of FULL CAS range and range-rate errors. On the basis of the statistical data analysis of such errors, the following assumptions are made:

(a) ΔR and $\Delta\dot{R}$ are independent, normally distributed random variables.

(b) For a specific set of environmental conditions, $E\,[\Delta\dot{R}]$, $\mathrm{Var}\,[\Delta\dot{R}]$, and $\mathrm{VAR}\,[\Delta R]$ are constant.

(c) The mean of ΔR is a function of R and $\dot{R}$, determined through regression analysis to be of the general form

$$E\,[\Delta R] = B_0 + B_1 R + B_2 \dot{R}$$

Two further assumptions are made in the model formulation to simplify the development:

(d) The aircraft are in a co-altitude condition.

(e) The closing rate, $\dot{R}$, is constant.

FULL CAS WARNING RANGE AND WARNING-RANGE ERROR

We shall evaluate the performance of CAS by evaluating the probability distribution of the range at which CAS provides a warning, assuming a constant $\dot{R}$ and the existence of a threat condition. We define the warning-range error as

$$R_\varepsilon = R_{CAS} - R_{STD} \qquad (1)$$

where

R_ε = warning range error

R_{CAS} = range at which CAS first provides a warning

For fixed $\dot{R}$, we can translate the range error into a warning-time error by the equation

$$T_{\varepsilon} = R_{\varepsilon}/\dot{R} \tag{2}$$

A value $T_{\varepsilon} > 0$ implies a premature or early alarm, and $T_{\varepsilon} < 0$ implies a delayed or late alarm.

The Tau threat criterion is such that for aircraft in a co-altitude condition a warning is given if

$$R \leq R_m \tag{3}$$

or

$$R \leq R_o + b\,\dot{R} \tag{4}$$

where

R_m = minimum range

R_o = offset range

b = slope of Tau line for $R > R_m$

Combining Equations 3 and 4, we have

$$R_{STD} = \max\,[R_m,\ R_o + b\dot{R}] \tag{5}$$

Note that $R_m = R_o + b\dot{R}$ when $\dot{R} = \dfrac{R_m - R_o}{b}$. If we let $\dot{R}^* = (R_m - R_o)/b$, we have

$$R_{STD} = \begin{cases} R_m, & \text{if } \dot{R} \leq \dot{R}^* \\ R_o + b\dot{R}, & \text{if } \dot{R} > \dot{R}^* \end{cases} \tag{6}$$

We now write the CAS measured values as follows:

$$\hat{R} = R + \Delta R \tag{7}$$

$$\hat{\dot{R}} = \dot{R} + \Delta\dot{R}$$

using a carat to denote such measurements.

CAS provides an alarm by the Tau criterion if $\hat{R} \leq R_o + b\hat{\dot{R}}$. If ΔR and $\Delta\dot{R}$ are constant, we have from Equation 7 that the alarm is first given at range $[R_o + b(\dot{R} + \Delta\dot{R}) - \Delta R]$. By the minimum-range criterion, CAS provides a warning if $\hat{R} \leq R_m$ or the alarm is first given at range $[R_m - \Delta R]$.

Therefore, if ΔR and $\Delta\dot{R}$ are constant,

$$R_{CAS} = \max \{[R_o + b(\dot{R} + \Delta\dot{R}) - \Delta R], [R_m - \Delta R]\} \tag{8}$$

or

$$R_{CAS} = \begin{cases} R_m - \Delta R \text{ if } \Delta\dot{R} \leq \dot{R}^* - \dot{R} \\ R_o + b(\dot{R} + \Delta\dot{R}) - \Delta R \text{ if } \Delta\dot{R} \geq \dot{R}^* - \dot{R} \end{cases} \tag{9}$$

For the warning-range error, we have, from Equations 6 and 9,

$$R_\varepsilon = \begin{cases} -\Delta R & , \dot{R} \leq \dot{R}^*, \ \Delta\dot{R} \leq \dot{R}^* - \dot{R} \\ R_o + b(\dot{R} + \Delta\dot{R}) - \Delta R - R_m & , \dot{R} \leq \dot{R}^*, \ \Delta\dot{R} > \dot{R}^* - \dot{R} \\ R_m - \Delta R - (R_o + b\dot{R}) & , \dot{R} > \dot{R}^*, \ \Delta\dot{R} \leq \dot{R}^* - \dot{R} \\ b\Delta\dot{R} - \Delta R & , \dot{R} > \dot{R}^*, \ \Delta\dot{R} > \dot{R}^* - \dot{R} \end{cases}$$

CAS WARNING-RANGE MODEL

To evaluate the range at which CAS provides a warning, we must recognize the fact that CAS does not measure range and range rate continuously but rather every three seconds, or, equivalently, the system determines whether a warning condition exists at true ranges R_1,

$$R_1 - \frac{\dot{R}}{1200}, \quad R_1 - \frac{2\dot{R}}{1200}, \text{ etc.}$$

where R_1 is the first range at which readings are taken. Since $\dot{R}$ is measured in knots, in 3 seconds the true range decreases by 3 x $\dot{R}/3600$ = $\dot{R}/1200$, which we shall denote by δ_R.

The fact that ΔR and $\Delta\dot{R}$ are random variables prohibits direct application of Equations 8 and 9. CAS might first provide a warning at Range R, and, because of the random nature of ΔR and $\Delta\dot{R}$, the warning might be "turned off" at $R - \delta_R$ the next range at which readings are taken. We will therefore define a random event [$R_w = R'$] representing the case of a CAS warning at range R'.

As shown above, the warning-range equation based on CAS measurements is a function of the value of $\Delta\dot{R}$. From Equation 9 we see that if $\Delta\dot{R} \leq \dot{R}^* - \dot{R} = C$ (say), the warning range is independent of the value of $\Delta\dot{R}$, but for $\Delta\dot{R} > C$, the warning range varies with $\Delta\dot{R}$.

We can therefore write the following equation:

$$P[R_w = R'] = P[\Delta\dot{R} \leq C]\, P[R_w = R' \mid \Delta\dot{R} \leq C] + \int_C^{\infty} f(\Delta\dot{R})\; P[R_w = R' \mid \Delta\dot{R}]\, d\Delta\dot{R} \tag{10}$$

where

R_w = a range at which CAS provides a warning

$C = \dot{R}^* - \dot{R}$

$f(\Delta\dot{R})$ = distribution of $\Delta\dot{R}$

From Equation 7 and the CAS criterion for alarm,

$$P[R_w = R'] = P[\Delta\dot{R} \leq C]\;\; P[\Delta R \leq R_m - R'] + \int_C^{\infty} f(\Delta\dot{R})\;\; P[\Delta R \leq R_o + b(\dot{R} + \Delta\dot{R}) - R']\, d\Delta\dot{R} \tag{11}$$

We now develop the equation for the probability of no warning up to and including range R'.

From Equation 11 we can find

$$P[\text{no warning at } R'] = 1 - P[R_w = R']$$

Then for initial CAS measurement at R_1 and continued measurements at $R_1 - j\delta_R$, where $\delta_R = \dot{R}/1200$, we have

$$P\{\text{no warning in } [R', R_1]\} = \prod_{j=o}^{J} [1 - P(R_w = R_1 - j\delta_R)] \tag{12}$$

where J is the greatest integer such that $R_1 - J\delta_R \geq R'$.

To obtain the probability distribution of the first CAS warning range R_{CAS}, we use the following equations:

$$P[R_{CAS} = R_1 - n\delta_R] = P\{\text{no warning in } [R_1 - (n-1)\delta_R, R_1]\} \times P[R_w = (R_1 - n\delta_R)]$$

$$= \prod_{j=o}^{n-1} \{1 - P[R_w = (R_1 - j\delta_R)]\} P[R_w = (R_1 - n\delta_R)] \qquad (13)$$

This equation implies independence of the events $[R_w = R_1 - j\delta_R]$, $j = 0,1,2...$ The limited experimental data available precluded testing for independence.

To obtain the expected range at which the first CAS warning is given, the following equation applies:

$$E\ [R_{CAS}] = \sum_{i=o}^{I} P[\text{first warning range} = (R_1 - i\delta_R)](R_1 - i\delta_R) \qquad (14)$$

where I is the largest integer such that $R_1 - I\delta_R \geq 0$.

MODEL QUANTIFICATION

We now utilize the results of the analysis of the R and $\dot{R}$ data to quantify the above models. This analysis has shown the following:

$$\Delta R \sim N[\ B_o + B_1\ R + B_2\ \dot{R},\ \sigma^2_{\Delta R}\ ]$$
$$\Delta\dot{R} \sim N[E(\Delta\dot{R}), \sigma^2_{\Delta\dot{R}}\ ]$$

Therefore, from Equation 11, we have

$$P[R_w = R'] = F_n [L_1] + F_N [L_2 - L_3 R']$$

$$+ \int_C^\infty \frac{1}{\sqrt{2\pi}\,\sigma_{\Delta\dot{R}}} e^{-\frac{1}{2\sigma^2_{\Delta\dot{R}}}[\Delta\dot{R} - E(\Delta\dot{R})]^2} F_N[L_4 + L_5 \Delta\dot{R} - L_3 R']\, d\Delta\dot{R} \qquad (15)$$

where

$$F_n(Z) = \int_\infty^Z \frac{}{\sqrt{2\pi}} e^{-z^2/2} dz$$

$$L_1 = \frac{C - E(\Delta\dot{R})}{\sigma_{\Delta\dot{R}}}$$

$$L_2 = \frac{R_m - B_o - B_2\dot{R}}{\sigma_{\Delta R}}$$

$$L_3 = \frac{1 + B_1}{\sigma_{\Delta R}}$$

$$L_4 = \frac{R_o + (b - B_2)\,\dot{R} - B_o}{\sigma_{\Delta R}}$$

$$L_5 = \frac{b}{\sigma_{\Delta R}}$$

It is seen that the second term of Equation 15 involves a complex double integral for which a closed-form solution does not exist. It can be approximated, however, as follows:

$$\int_C^{\infty} \frac{1}{\sqrt{2\pi}\ \sigma_{\Delta\dot{R}}}\ e^{-\frac{1}{2\ \sigma_{\Delta\dot{R}}}\ [\Delta\dot{R} - E(\Delta\dot{R})]^2}\ F_n[L_4 + L_5\ \Delta\dot{R} - L_3R']d\Delta\dot{R}$$

$$\approx \sum_{k=o}^{K} \left\{ F_N \left[\frac{C+(k+1)d - E(\Delta\dot{R}]}{\sigma_{\Delta\dot{R}}}\right] - F\left[\frac{C+kd-E(\Delta\dot{R})}{\sigma_{\Delta\dot{R}}}\right] \right. \tag{16}$$

$$\times \quad F[L_4 + L_5(C+kd+d/2) - L_3R']$$

where d is a preselected (small) increment for $\Delta\dot{R}$ to approximate $d\Delta\dot{R}$, and K is an integer such that $F_N \left[\frac{C+(K+1)d - E(\Delta\dot{R})}{\sigma_{\Delta\dot{R}}}\right] \approx 1.0$

A computer program in timesharing FORTRAN has been written to evaluate Equations 15 and 16 and then to apply the no-warning probability model given by Equation 12 and the first-warning probability given by Equation 13.

APPENDIX G

TRAFFIC SIMULATOR

This appendix presents the McDonnell Douglas description of the traffic simulator used in the CAS test and evaluation.

TRAFFIC SIMULATOR

The traffic simulator has been designed to work in conjunction with the T&E to provide simulation of from 250 to 2000 aircraft in various combinations of slots. It generates a pulse which is 8 microseconds wide and is timed to occur just beyond the altitude band. The received pulse is interpreted by the collision avoidance system as a back up mode response which will cause the system to search for another slot which is unoccupied.

The T&E transmitter was designed for a comparatively low duty cycle; therefore, the power output drops as the number of simulated aircraft increases. As a result, the limitation on number of aircraft to be simulated is a function of the range of operation required. The simulation of 500 aircraft causes a 2 dB drop in power output which will have minor effect on range. However, simulating 1000 aircraft causes the power to drop by approximately 13.6 db which reduces the effective range to 15 or 20 miles. Refer to figure 1 to determine power output for a selected number of simulated aircraft.

The traffic simulator has an ON/OFF switch, a rotary selector switch and 14 toggle switches to control combinations of slots in which the 8 microsecond pulse is transmitted. These combinations are as follows:

a) Selector Switch is position 1. Transmission will occur in 1000 slots with 3 consecutive slots filled and 3 consecutive slots empty, starting with frequency f_1.

b) Selector Switch in position 2. Transmission will occur in 1000 slots which are the complement of the slots filled in switch position 1.

c) Selector Switch is position 3. Transmission will occur in 666 slots, using every third slot starting with frequency f_2.

d) Selector Switch in position 4. Transmission will occur in 666 slots, using every third slot starting with frequency f_2.

e) Selector Switch in position 5. Transmission will occur in 666 slots, using every third slot starting with frequency f_3.

f) Selector Switch in position 6. Transmission will occur in the slots associated with the frequency selected (f_1, f_2, f_3 or f_4). An additional switch, the every/every other f_x slot switch, makes it possible to leave every other f_1, f_2, f_3 or f_4 slot empty. Any combination of f_1, f_2, f_3 or f_4 may be selected simultaneously.

g) Selector Switch in position 7. Transmission will occur in 1840 slots, leaving only ten groups of six empty slots each remaining. The ten groups of slots can be filled selectively, using the "n = 0" thru "n = 9" switches, or by the f_1, f_2, f_3 or f_4 switches, or by any combination.

To assist in determining which slots will be filled when a particular switch is thrown, a set of tables has been prepared as drawing H1X002-8A. On page 1, message slots 0 thru 575 are presented; on page 2, 576 thru 1151; on page 3, 1152 thru 1727; and on page 4, 1728 thru 1999.

The "Aircraft simulated" switch positions (1) thru (6) are directly cross referenced. For instance, if the aircraft simulated switch position (4) is selected, on page 1, f_3 slots 1, 73, 145, 217, 289, 361, 433, 505, f_2 slots 5, 77, 149, 221, 293, 365, 437, 509, f_1 slots 8,80, 152,etc will be filled with a simulated airplane. The "E" and "EO" referenced under switch position 6 refers to the "every f_x" and every other f_x" switch position, respectively.

Switch position 7 shows that every slot is filled except the three outlined blocks of 156 thru 161, 348 thru 353 and 540 thru 545 on page 1. Slots 156 thru 161 can be filled as a group by activating switch "n = 0"; or slots 156 and 160 can be filled by switches "E + f_1 (every f_1 slot); slots 157 and 161 can be filled by "E + f_2 ; slot 158 can be filled by "E + f_3"; slot 159 can be filled by "E + f_4"; slot 160 can be filled by "EO + f_1" (every other f_1 slot); slot 161 can be filled by "EO + f_2"; or any desired combination of E + f_x or EO + f_x can be used to selectively fill the slots. The E + f_x or EO + f_x switches affect all groups of remaining empty slots the same. The "n = 0" thru "n = 9" switches are each dedicated to a particular group of slots.

For information purposes, the ground station obstacle avoidance and landing aid slots are shown as shaded.

Drawing H1X002-8 is a wiring diagram of the traffic simulator.

T&E POWER OUTPUT

VS

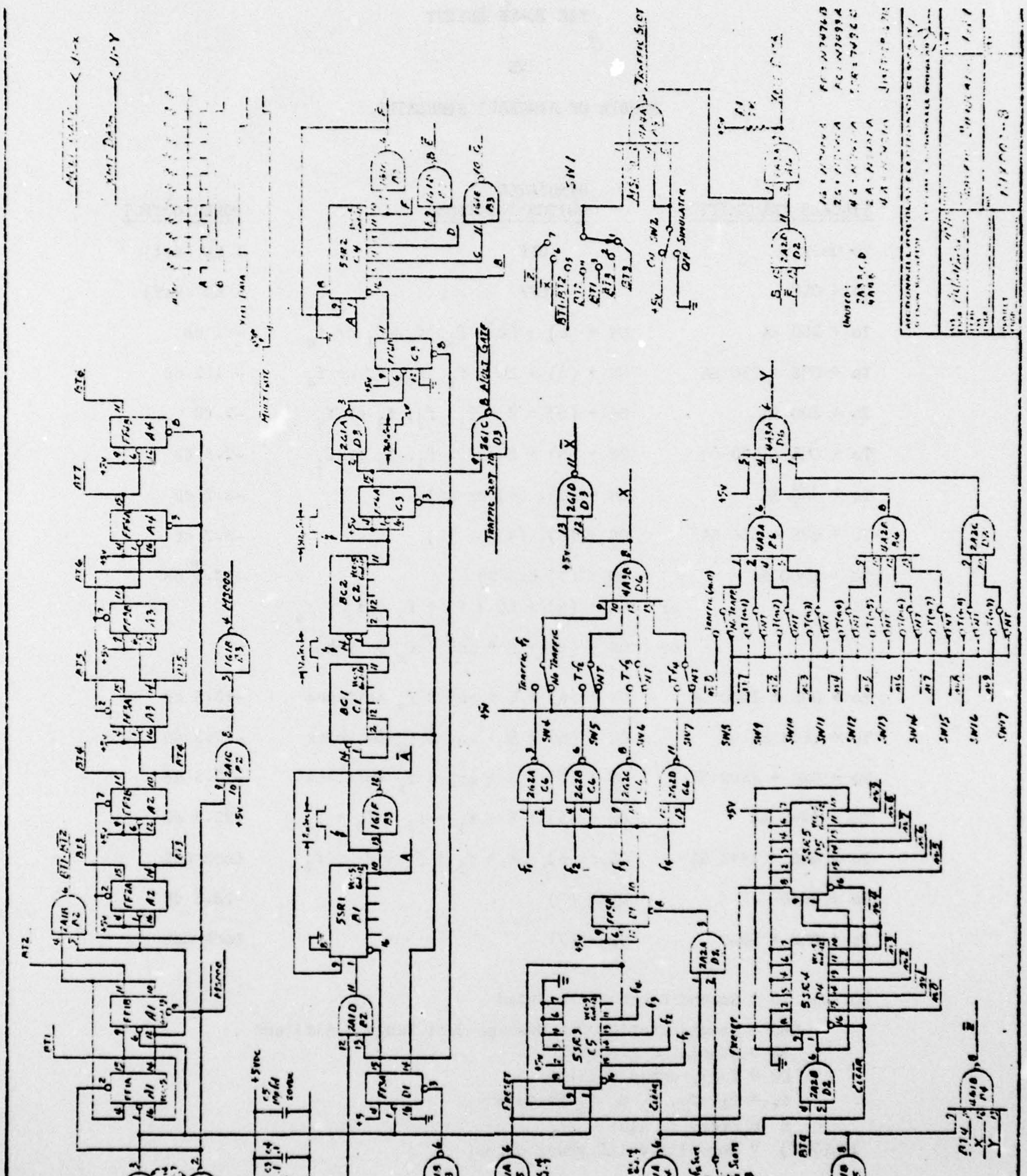
NUMBER OF AIRCRAFT SIMULATED

SIGNALS TRANSMITTED		SIMULATOR SWITCH POSITIONS	POWER OUTPUT
To Only		OFF	1 KW (Ref)
To + OMS		OFF	1 KW (Ref)
To + 250 SA		ON + (6) + EO + f_1, f_2, f_3 or f_4	- 1 dB
To + OMS + 250 SA		ON + (6) + EO + f_1, f_2, f_3 or f_4	- 1.2 dB
To + 500 SA		ON + (6) + E + f_1, f_2, f_3 or f_4	-2 dB
To + OMS + 500 SA		ON + (6) + E + f_1, f_2, f_3 or f_4	-2.3 dB
To + 666 SA		ON + (3), (4) or (5)	-3.2 dB
To + OMS + 666 SA		ON + (3), (4) or (5)	-3.2 dB
To + 1000 SA		ON + (1) or (2)	-13.6 dB
	or	ON + (6) + EO + f_1 + f_2 + f_3 + f_4	
	or	ON + (6) + E + any 2 f_x switches	
To + OMS + 1000 SA		ON + (6) + E + any 2 f_x switches	-13.6 dB
To + 1500 SA		ON + (6) + E + any 3 f_x switches	-17.5 dB
To + OMS + 1500 SA		ON + (6) + E + any 3 f_x switches	-17.5 dB
To + 1999 SA		ON + (6) + E + f_1 + f_2 + f_3 + f_4	-23.5 dB
To + OMS + 1998 SA		ON + (6) + E + f_1 + f_2 + f_3 + f_4	Lock Out
To + 1840		ON + (7)	-23.5 dB
To + OMS + 1840		ON + (7)	Lock Out

NOTES: To = Ground Epoch Start Triad
OMS = Ground Station Own Message Slot Range & Altitude
SA = Simulated Aircraft
EO = Every other f_x slot
f_x = f_1, f_2, f_3 or f_4 frequency
E = Every f_x slot
1KW(Ref) = Normalized T&E power output

FIGURE 1

BEST AVAILABLE COPY



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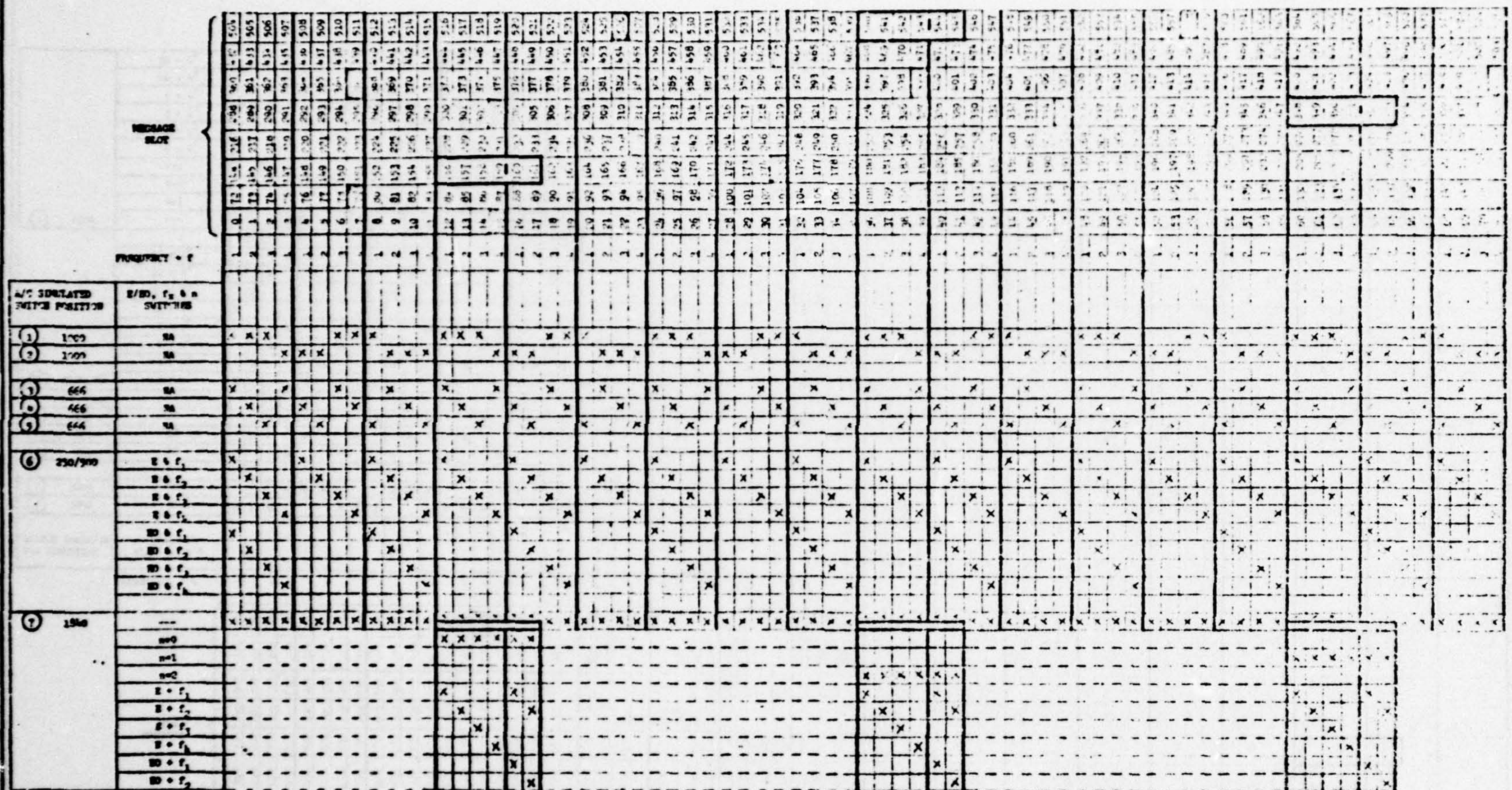

Notes:

- [X] = *Simulated Aircraft*
- = *Ground Station Obstacle Avoidance & Landing Aid Slots*
- = *Ground Station Test Message Slots*

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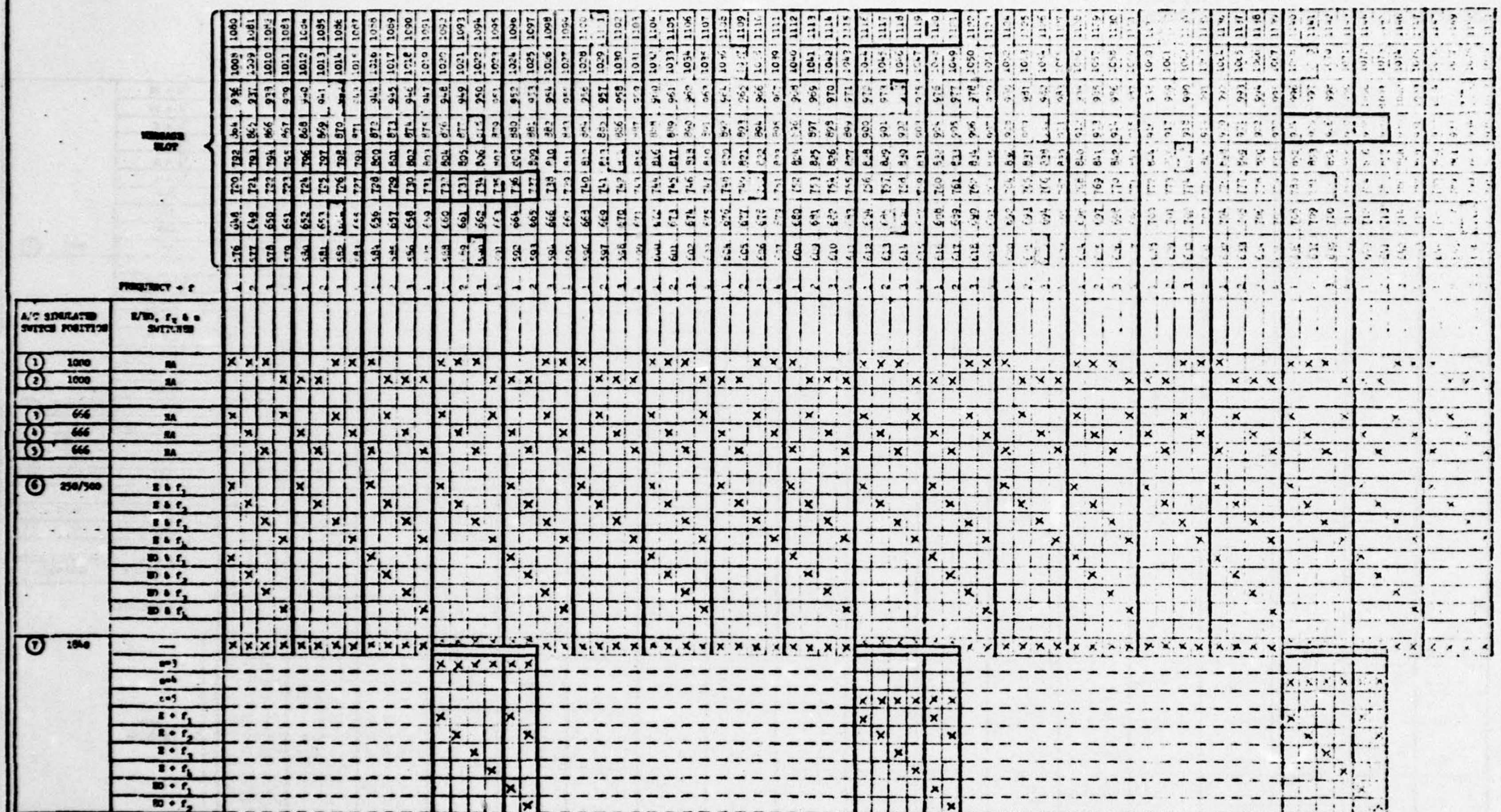

NOTES:
SIMULATED AIRCRAFT
= GROUND STATION OBSTACLE AVOIDANCE & LANDING AID SLOTS
= GROUND STATION TEST MESSAGE SLOTS

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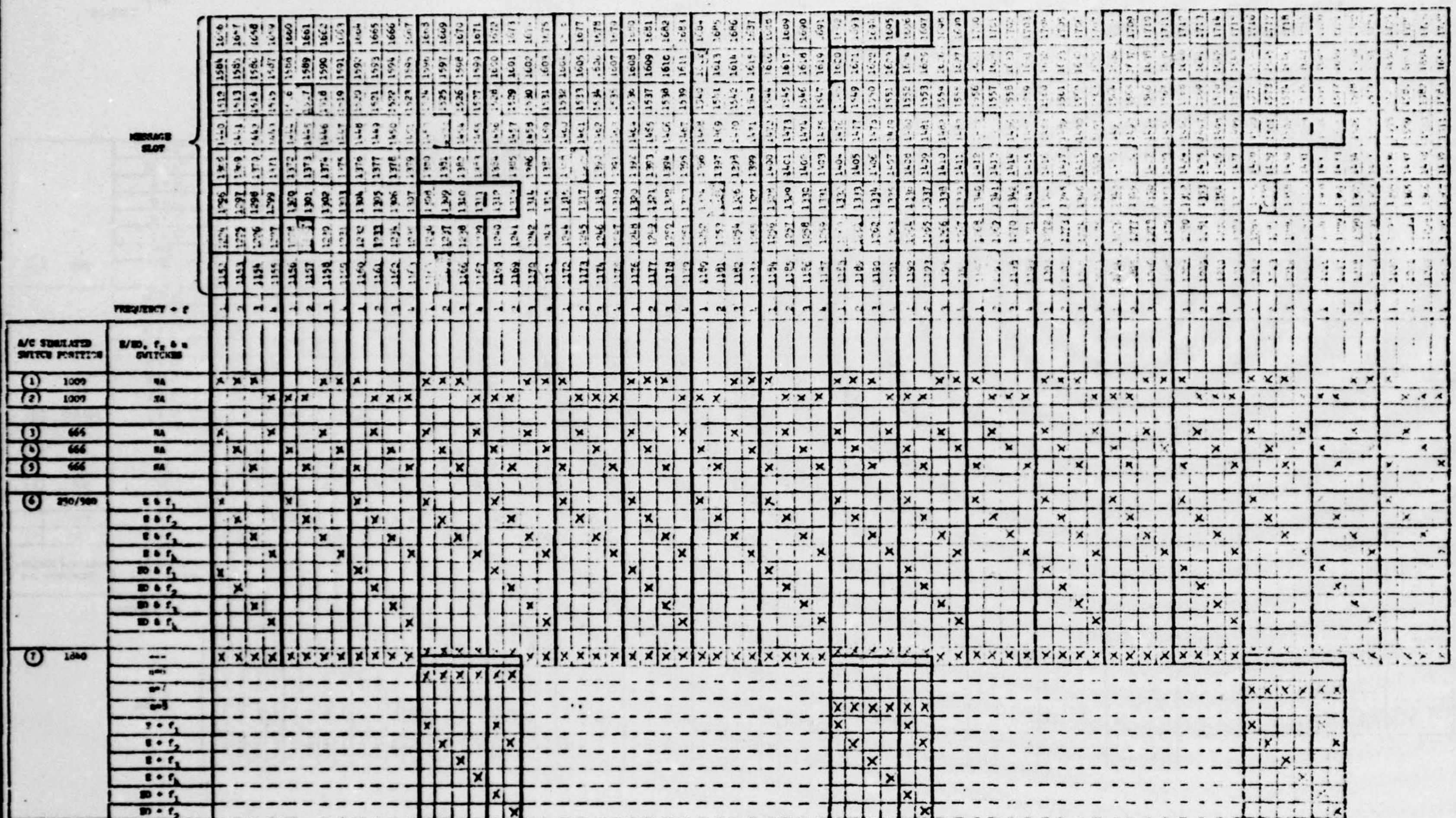
H1X 992-8A



NOTES:

[X] = SIMULATED AIRCRAFT

[ ] = GROUND STATION OBSTACLE AVOIDANCE & LANDING AID SLOTS

[ ] = GROUND STATION TEST MESSAGE SLOTS

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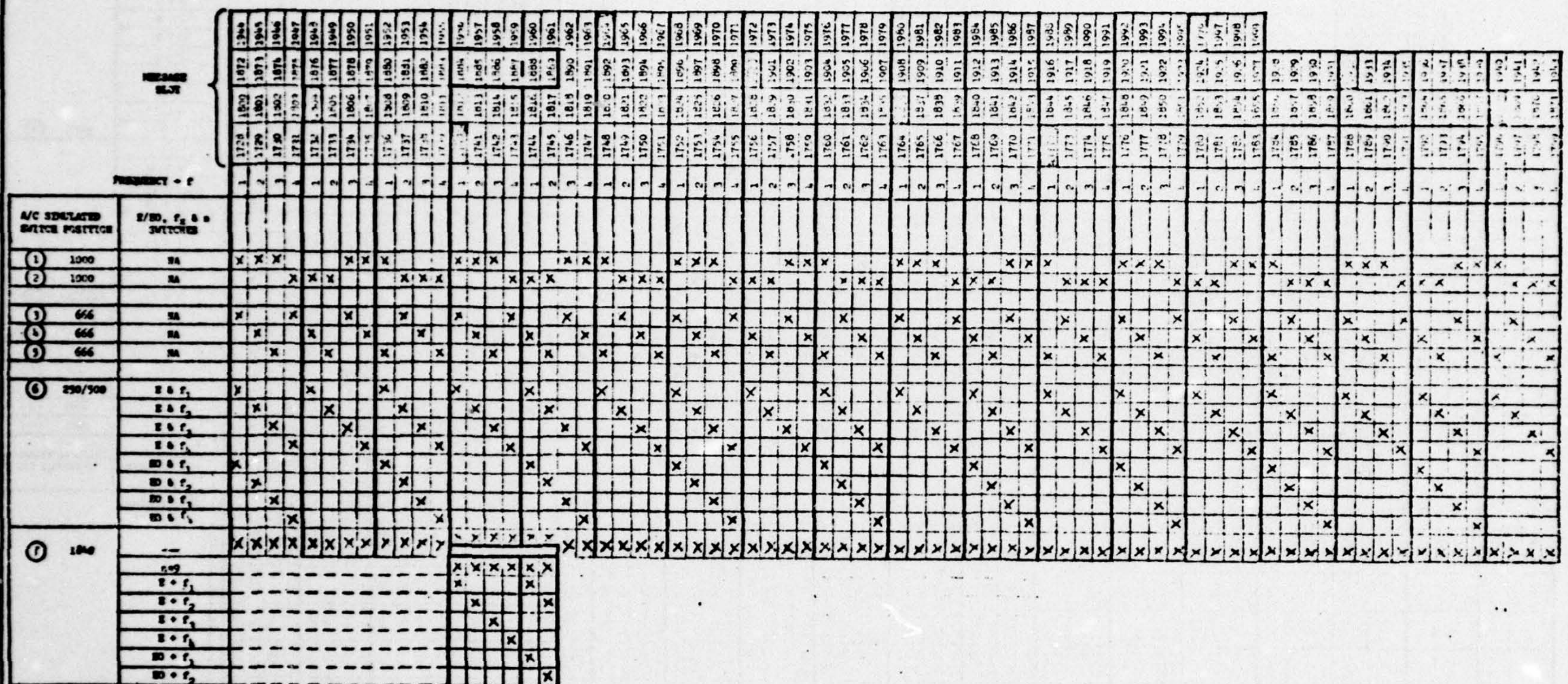

NOTES:

[X] = SIMULATED AIRCRAFT

[ ] = GROUND STATION OBSTACLE AVOIDANCE & LANDING AID SLOTS

[ ] = GROUND STATION TEST MESSAGE SLOTS

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SYS ENGR [signature]	TITLE: TRAFFIC SIMULATION
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PROJECT ENGR	

APPENDIX H

PHOTOGRAPHS OF CAS INSTALLATIONS

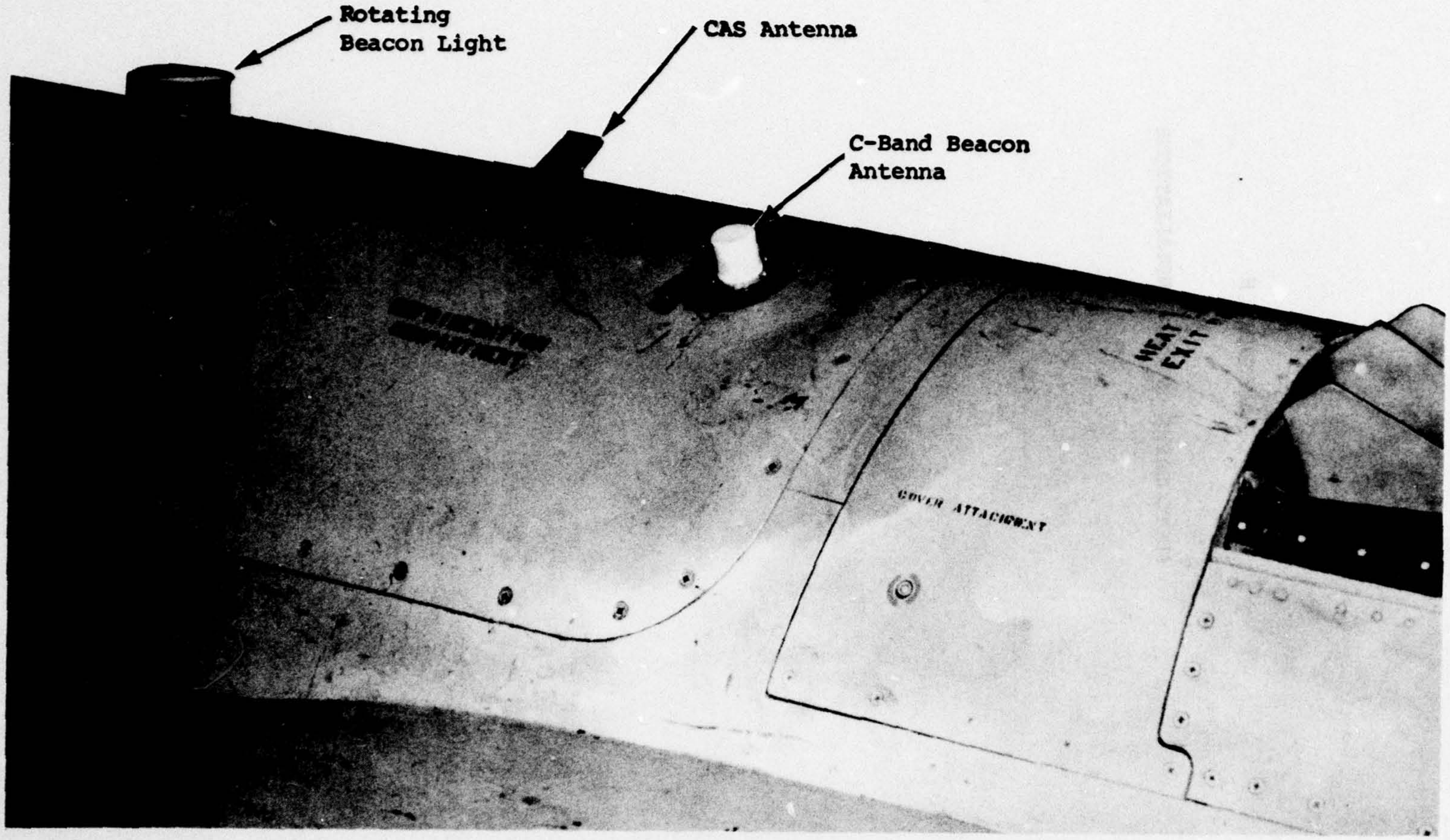

Figure H-1. F-106A UPPER ANTENNA INSTALLATION

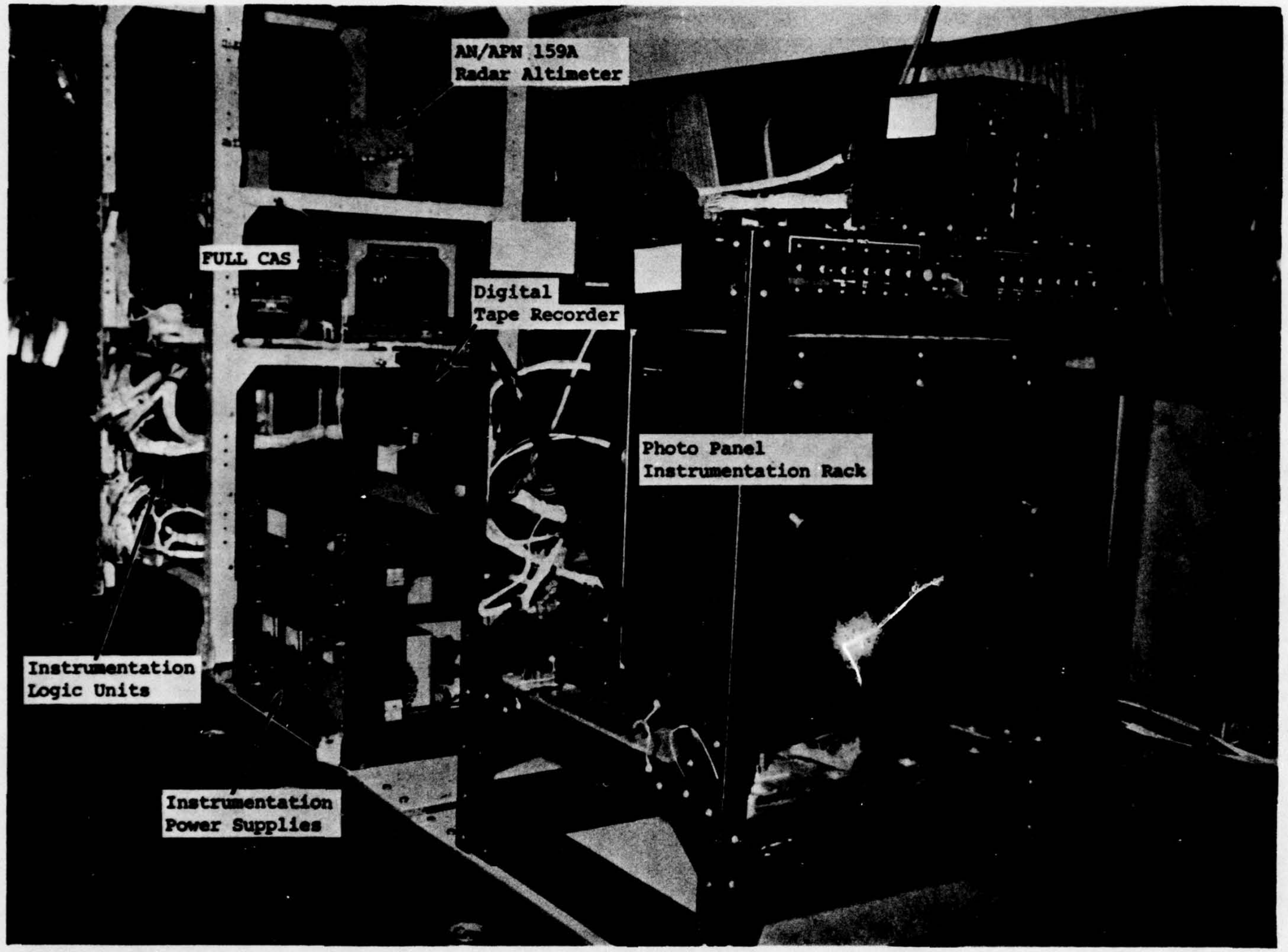

Figure H-3. C-131B INSTALLATION OF FULL CAS AND INSTRUMENTATION

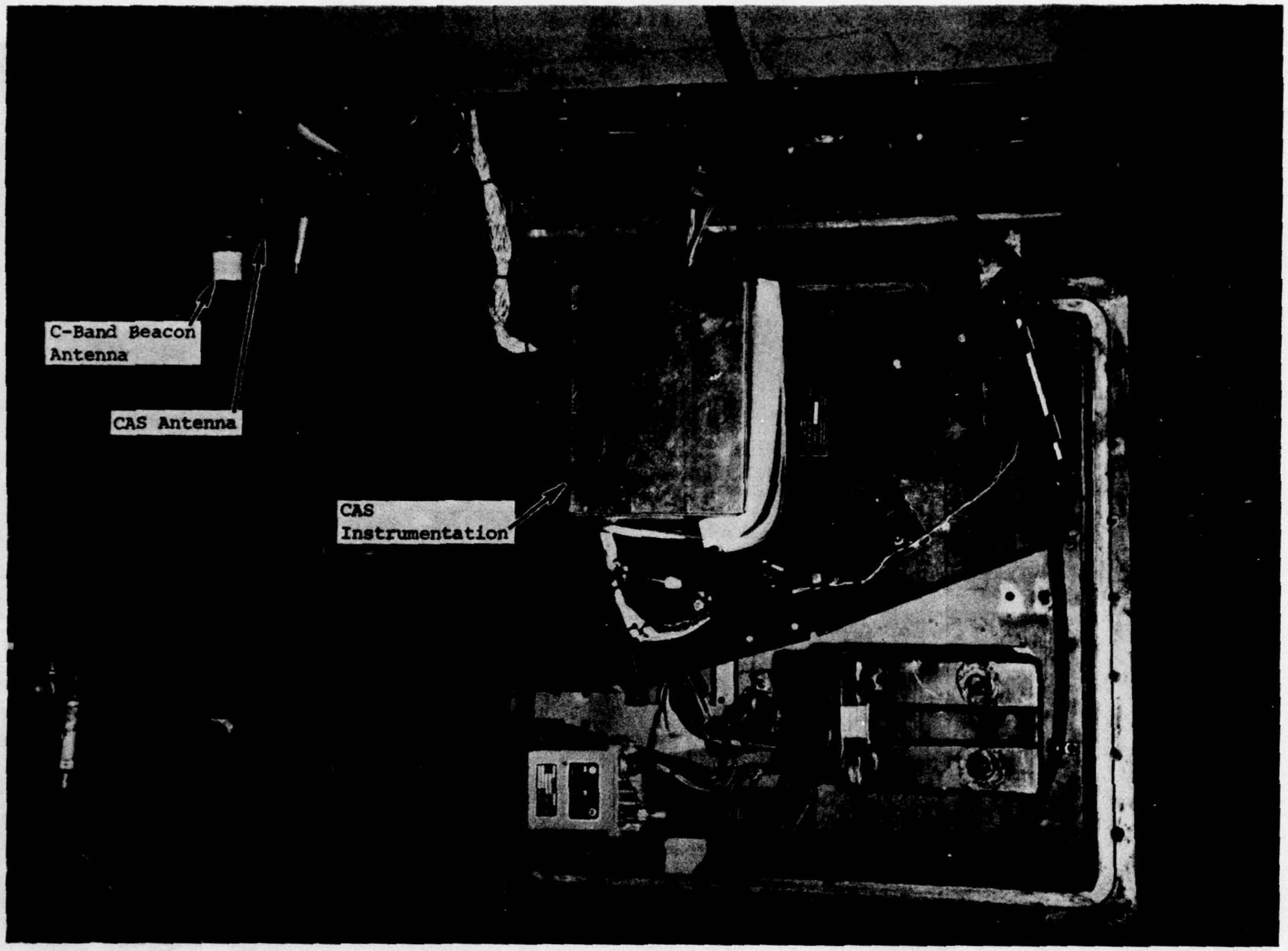

Figure H-2. **F-106A LOWER ANTENNA AND CAS INSTRUMENTATION**

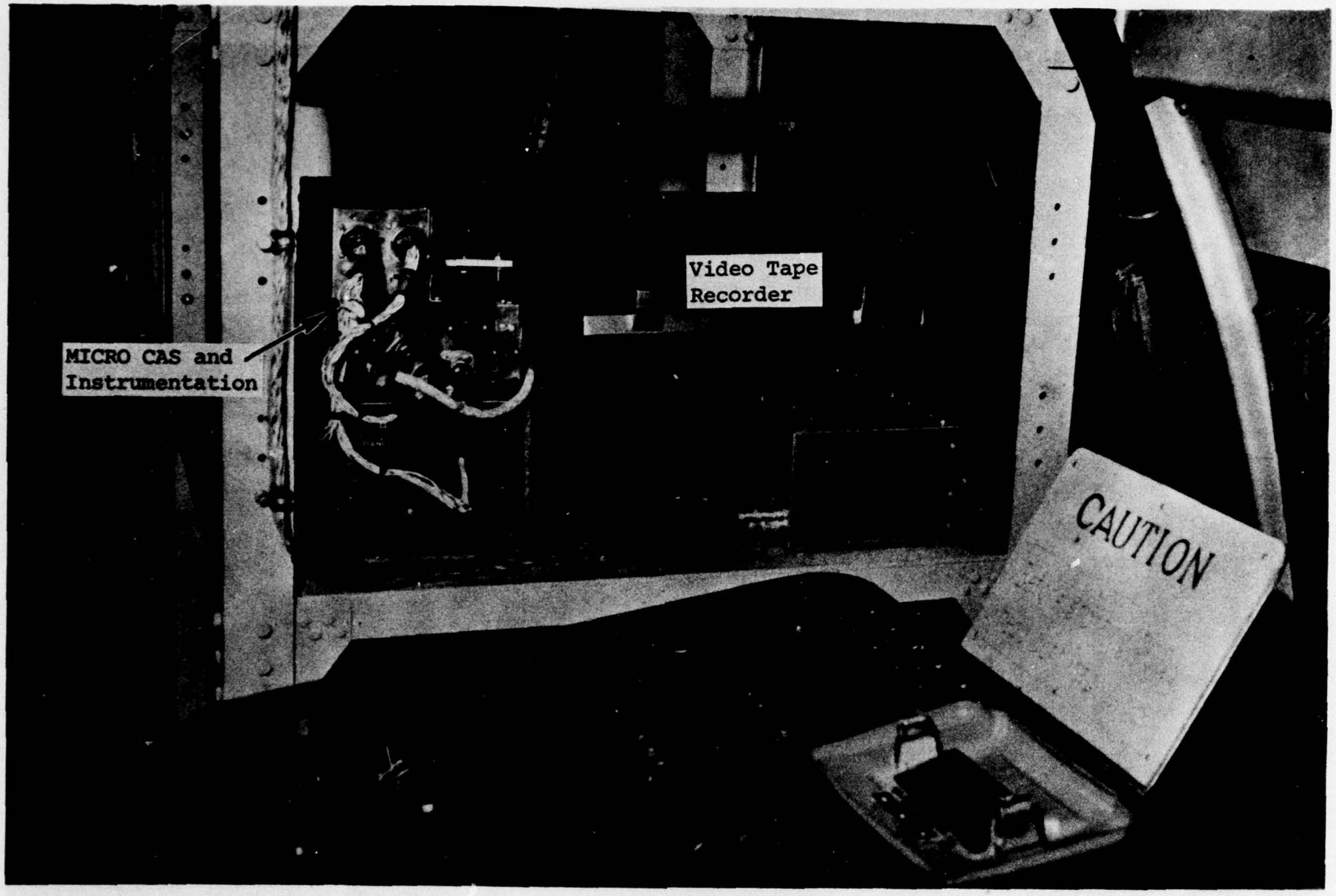

Figure H-4. C-131B INSTALLATION OF MICRO CAS

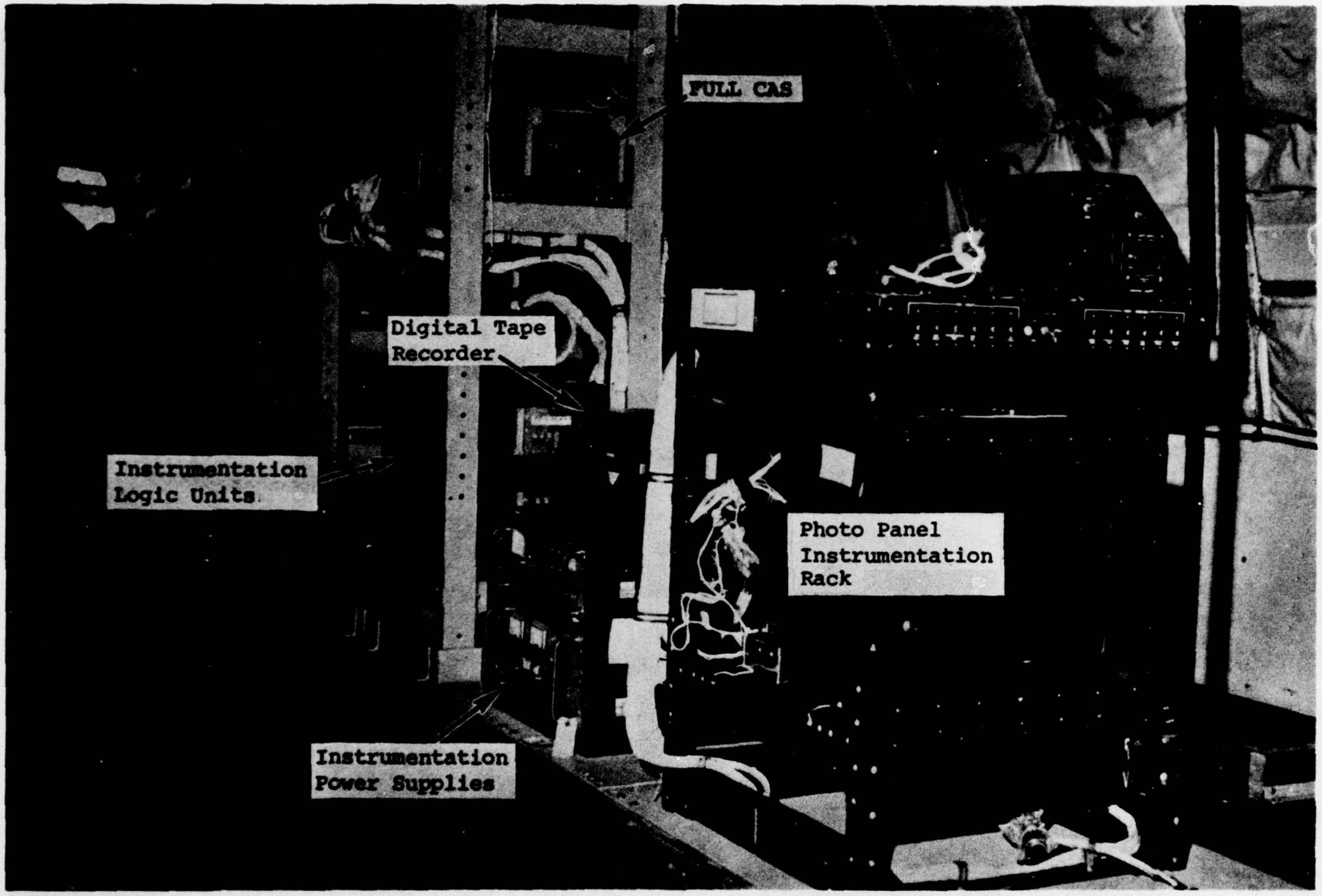

Figure H-5. **NKC-135 INSTALLATION OF FULL CAS AND INSTRUMENTATION**